ENVIRONMENTAL HEALTH RISKS ASSOCIATED WITH FIREWOOD INDUCED VOLATILE ORGANIC COMPOUNDS IN SENWABARWANA VILLAGES, REPUBLIC OF SOUTH AFRICA

by

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DECLARATION

I declare that Environmental health risks associated with firewood induced volatile organic compounds in Senwabarwana Villages, Republic of South Africa, is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

I further declare that I submitted the thesis to originality checking software and that it falls within the accepted requirements for originality.

I further declare that I have not previously submitted this work, or part of it, for examination at UNISA for another qualification or at any other higher education institution."

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SIGNATURE

DATE

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To God be the glory, the one who sustains me. He surrounded me with the following giants to accomplishment this work:

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DISCLAIMER

Generally, all the chapters of this thesis have been published or presented or submitted to an accredited and peer reviewed journal or conference, except chapter one (1), three (3) and seven (7). Each chapter is referenced according to the prescribed format of the journal or conference proceeding in which it was presented, published and/or submitted.

LIST OF ACRONYMS AND ABBREVIATIONS

µg	Microgram
DoE	Department of Energy
DoH	Department of Health
FAO	Food and Agricultural Organisation
EHRA	Environmental Health Risk Assessment
IEA	Independent Energy Access
IEHRA	Integrated Environmental Health Risk Assessment
LPG	Liquified Petroleum Gas
MRLs	Minimal Risk Levels
OECD	Organisation for Economic Co-operation and Development
SKC	Scientific Kit Cooperation
StatsSA	Statistics South Africa
VOCs	Volatile Organic Compounds
WHO	World Health Organisation

ABSTRACT

Firewood is a dominant household fuel type used in many developing countries. Even in countries where there is improved access to electricity, most households still rely on firewood for their energy needs. Harvesting of some wood is illegal, however the high poverty rate, absence of alternative fuels and lack of law enforcement means even the protected wood species will continue to be used, with consequent pressure on the forests. Furthermore, the combustion of firewood for domestic use takes place in poorly ventilated homes emitting hazardous pollutants, which causes indoor air pollution and affect human health.

The use of firewood as a household fuel can be superimposed nearly perfectly on that of socio-economic development. Additionally, the use of household firewood is invariably associated with poverty in countries, in communities within a country and in households within a community. Indoor air pollution studies on human health should then consider socio-economic factors which seem to be one of the determinants of both firewood use and ill health, a determinant which is often neglected in most indoor air pollution studies. Domestic inhalation of firewood smoke is one of the mechanisms linking socio-economic (poverty) to disease.

The current study sought to determine a baseline of wood usage and health risks caused by volatile organic compounds in Senwabarwana villages. This study integrated observations, ethnobotanical meta-analysis and experimental into one comprehensive integrated environmental health risk assessment framework to assess the risks associated with exposure to volatile organic compounds from firewood combustion. Basic information about firewood usage, socio-economic dynamics and perceived health problems related to volatile organic compounds was collected using a structured questionnaire. The Vac-U-Chamber was used to sample the air.

The results show that firewood is extensively used in poorly ventilated kitchens for cooking and home heating in Senwabarwana villages. Ten priority firewood plant species are frequently used in the study area, namely Mohweleri (*Combretum apiculatum*), Moretshe *(Dichrostachys cinera*), Motswiri (*Combretum imberbe*), Mokgwa (*Acacia burkei*), Mushu (*Acacia tortilis*), Motshe (*Cussonia paniculate*), Mokata (*Combretum hereroense*), Mphata (*Lonchocarpus capassa*), Mokgalo (*Ziziphus mucronate*) and Mogwana (*Grewia monticola*), in their order of preference. The results also indicated thirteen common reasons or factors that influence the choice of firewood plant species by households, the main four being: (i) the embers formed during combustion, (ii) heat value, (iii) low ash content and (iv) availability of the firewood plant species. Further analysis revealed several uses and ranking thereof, including reviewing the national status and legal profile of each identified plant species. The study found that most of the firewood species used in Senwabarwana Village were indigenous. Major drivers of firewood use are household income, educational status of breadwinners, family sizes, and place of residence, fuel affordability and accessibility, among others.

Concentrations of benzene, toluene, ethylbenzene and xylene per plant species were studied to assess the risk exposed to the Senwabarwana community. Literature indicates that these pollutants have several health effects associated with acute exposure such as eye, nose and throat irritation, headaches, dizziness, nausea and vomiting. Both hazard quotient and hazard index were found to be less than one indicating no risk exists with the use of plant species used for firewood in Senwabarwana even to sensitive individuals. The risk of developing health effects due to the presence of the studied volatile organic compounds can be assessed as negligible.

Since firewood is a more convenient source of energy, it is recommended that the size of the windows be extended for ventilation. Agroforesty should also be implemented as a conservation method. The wood that emits less concentration of pollutants be used for firemaking.

Keywords: Indoor air pollution; Environmental health; Environmental health risks; Ethnobotanical phenomenology; Indigenous criteria for firewood selection; Integrated environmental health risk assessment; Exposure assessment; Firewood; Firewood harvesting; Risk assessment; Tree species used for firewood; Volatile Organic Compounds.

SETSOPOLWA

Dikgong ke mohuta wo o šomišwago kudu wa dibešwa tša ka gae ka dinageng tše ntši tšeo di hlabologago. Le ka dinageng tšeo go nago le phihlelelo ye e kaonafetšego go mohlagase, malapa a mantši a sa tshephile dikgong bjalo ka dinyakwa tša ona tša enetši. Le ge e le gore go rwalela dikgong tše dingwe ga go molaong, dipalopalo tša godimo tša bohloki, go hlokega ga dibešwa tše dingwe le tlhokego ya phethagatšo ya molao go baka gore le mehuta ya dikgong yeo e šireleditšwego e šomišwe, gomme se se dira gore dithokgwa di bewe ka fase ga kgatelelo. Godimo ga fao, le ge e le gore go tšhungwa ga dikgong bjalo ka mollo ka gae go direga ka dintlong tšeo di hlokago tsenyo ya moya, gomme ka go realo se sa tšweletša dišilafatšamoya tše kotsi, se se baka tšhilafatšo ya moya ka gare ga dintlo gomme sa ama maphelo a batho.

Tšomišo ya dikgong bjalo ka dibešwa tša ka gae go ka amanywa kudu le taba ya tlhabollo ya ekomoni ya setšhaba. Godimo ga fao, tšhomišo ya dikgong ka malapeng go amanywa kudu ka dinageng, ka ditšhabeng tša ka nageng le ka malapeng a ka setšhabeng. Dinyakišišo ka ga tšhilafatšo ya moya ka gare ga dintlo mabapi le maphelo a batho ka fao di swanetše go hlokomela mabaka a ekonomi ya setšhaba e lego seo se bonalago e le seo se bakago bobedi tšhomišo ya dikgong le maphelo a batho ao a fokolago, e lego selo seo se bakago maphelo ao a fokolago seo gantši se hlokomologwago ka dinyakišišong tše ntši tša tšhilafatšo ya moya. Go hema moši wa dikgong ka gae ke ye nngwe ya mekgwa yeo e amantšhago maemo a ekonomi ya setšhaba (bohloki) le malwetši.

Dinyakišišo tše di nyaka go utolla motheo wa tšhomišo ya dikgong le dikotsi tša maphelo tšeo di bakwago ke dinokolwane tša tlhago ka metseng ya ka Senwabarwana. Dinyakišišo tše di kopantše ditekodišišo, tshekatsheko ya dinyakišišo tša peleng ka ga dimela tša tlhago le tekolo ka go tlhakokakaretšo ye e kopantšwego ya tshekatsheko ya dikotsi ye e kopantšwego go maphelo a tikologo ka nepo ya go dira tshekatsheko ya go kopana le dinokolwane tša tlhago tšeo di fetogago gabonolo ka lebaka la go bešwa ga dikgong. Tshedimošo ya motheo mabapi le tšhomišo ya dikgong, maemo a ekonomi ya setšhaba le mathata a tša maphelo ao a bonwago a go amana le dinokolwane tša tlhago tšeo di fetogago gabonolo e kgobokeditšwe ka go šomiša lenaneo la dipotšišo tša dinyakišišo tšeo di beakantšwego ka maleba. Vac-U-Chamber e šomišitšwe go dira sampole ya moya.

Dipoelo di bontšha gore dikgong di šomišwa kudu ka mafelong a go apeela ao a hlokago tsenyo ya moya le go ruthufatša dintlo ka metseng ya ka Senwabarwana. Go na le mehuta ye lesome ya dimela tšeo di šomišwago kudu bjalo ka dikgong ka lefelong leo go dirwago dinyakišišo, yona ke Mohweleri (Combretum apiculatum), Moretshe (Dichrostachys cinera), Motswiri (Combretum imberbe), Mokgwa (Acacia burkei), Mushu (Acacia tortilis), Motshe (Cussonia paniculate), Mokata (Combretum hereroense), Mphata (Lonchocarpus capassa), Mokgalo (Ziziphus mucronate) le Mogwana (Grewia monticola), go ya ka tatelano ya ka fao e ratwago ka gona bjalo ka dikgong. Dipoelo di laeditše gore go na le mabaka goba dintlha tše lesomenne tše di tlwaelegilego tšeo di huetšago kgetho ya mehuta ya dimela tšeo bjalo ka dikgong ke malapa, gomme mabaka a mane a magolo ona ke: (i) magala ao a hlamegago ka nakong ya ge di bešitšwe, (ii) boleng bja phišo, (iii) go ba le molora o monnyane le (iv) go hwetšagala ga mehuta ya mehlare yeo bjalo ka dikgong. Tshekatsheko ye nngwe e utollotše mehutahuta ya tšhomišo ya dikgong le maemo a tšona gona fao, go akaretšwa le go lekodišiša maemo a bosetšhaba le phrofaele ya tša semolao ya mohuta o mongwe le o mongwe wa semela seo se utollotšwego. Dinyakišišo di utollotše gore bontši bja mehuta ya dimela tšeo di šomišwago ka Motseng wa Senwabarwana ke ya tlhago. Dilo tše kgolo tšeo di hlohleletšago go šomišwa ga dikgong ke, gareng ga tše dingwe, letseno la ka lapeng, maemo a thuto a bao ba hlokometšego malapa, bogolo bja malapa, lefelo la bodulo, le go kgona go lefela dibešwa le go di fihlelela.

Go ba gona ga pensini, toluene, ethylbenzene le xylene ka go mohuta wa semela go ile gwa nyakišišwa ka nepo ya go sekaseka kotsi yeo setšhaba sa Senwabarwana se lego go yona. Bobedi dipalopalo tša kotsi le diteng tša kotsi di hweditšwe gore di ka fase ga tee, gomme se se laetša gore ga go na kotsi ye e lego gona mabapi le kgetho ya mehuta ya mehlare ye e šomišwago bjalo ka dikgong ka Senwabarwana, le ge e ka ba go batho bao ba ka amegago gabonolo. Kotsi ya go ba le diabe tša kamego ya maphelo ka lebaka la go ba gona ga dinokolwane tša tlhago tšeo di nyakišišitšwego e ka sekasekwa bjalo ka go hloka šedi.

Mantšu a bohlokwa: Tšhilafatšo ya moya ka gare ga dintlo; Maphelo a tikologo; Dikotsi go maphelo a tikologo; Tshekatsheko ya dinyakišišo tša peleng ka ga dimela tša tlhago; Kgetho ya mehuta ya dimela tša tlhago tšeo di ka šomišwago bjalo ka dikgong; Tshekatsheko ye e kopantšwego ya dikotsi go maphelo a tikologo; Tshekatsheko ya go kopana le dinokolwane; Dikgong; Rwalela dikgong; Tshekatsheka ya dikotsi; Mehuta ya mehlare ye e šomišwago bjalo ka dikgong; Dinokolwane tša Tlhago tšeo di Fetogago Gabonolo.

NKOMISO LOWU NGA NA VUXOKOXOKO BYA NDZAVISISO WA DYONDZO

Tihunyi i muxaka wa vutshiveri ngopfu emindyangwini lowu tirhisiwaka ngopfu eka matiko manyingi lama ya ha hluvukaka. Hambi ematikweni lama ya nga na gezi, mindyangu minyingi ya ha tirhisa tihunyi ku hlanganyetana na swilaveko swa yona swa eneji. Hambi loko ku hlengetela mirhi yo karhi swi nga pfumeleriwangiku hi nawu, kambe xiyenge xa le henhla xa vusweti, ku kala ka switirhisiwa swin'wana swa ku tshivela, na ku va va nawu va nga koti ku sindzisa ku landzeleriwa ka nawu, swi endla leswo mixaka ya mirhi leyi nga sirheleriwa yi hela hi ku tirhisiwa, leswi swi vangelaka ntshikilelo eka swihlahla. Nakambe, ku tshiveriwa ka tihunyi ekaya swi humelela eka minyangu ya vusweti laha ku nga ri ku na mafasitera yo humesa musi no nghenisa moya, leswi swi vangeleka ku va na mimusi ya nghozi, no thyakisiwa ka moya lomu makaya leswi swi vangelaka swirhalanganyi swa rihanyu eka vanhu.

Ku tirhsiwa ka tihunyi ku tshivela lomu makaya swi nga va na swikavanyeti swa nkoka eka nhluvuko wa vanhu na swa ikhonomi. Tlhandlakambirhi, ku tirhisiwa ka tihyunyi swi fambelana na ku tirhisiwa ematikweni ya vusweti, eka tindhawu ta vaaki etikweni na le ka mindyangu ya vusweti lomu ka tindhawu ta vaaki. Tidyondzo hi ku thyakisiwa ka moya swi na swirhalanganyi swa rihanyu eka vanhu, leswi swi fanele ku kambisisiwa eka swiyimo swa vanhu na ikhonomi leswi swi nga na ku kotlana exikarhi ka ku tirhisiwa ka tihunyi na rihanyu leri nga ri ku lerinene eka vanhu, kasi leswi a swi tali ku tekeriwa enhlokweni eka tidyondzo to tala ta nthyakiso wa moya loku endlekaka lomu makaya. Ku hefemula musi wa tihunyi lomu makaya hi xin'wana xavangelo lexi kotlanisaka ku khumbana na vanhu na ikhonomi (vusweti) na mavabyi.

Dyondzo ya ndzavisisi leyi endliwaka seswi yi na xikongomelo xa ku vona ku kotlana ka ku tirhisiwa ka tihunyi na tinghozi ta rihanyu leyi yi endliwaka eka tindhawu ta le makaya ta le Senwabarwana. Dyondzo leyi ya ndzavisiso yi katse ku langutisa kunene, nxopanxopo wa ethnobotanical meta-analysis na xipirimente na ku xopaxopa vunghozi bya rihanyu eka mbangu ku kambela tinghozi leti fambisanaka na organic compounds eka ku tshiveriwa ka tihunyi. Vutivi bya masungulo bya nkoka hi ku tirhisiwa ka tihunyi, leswi khumbanaka na vanhu na ikhonomi na leswi swi voniwaka swi ri swirhalanganyi eka swa rihanyu leswi swi fambelanaka na ku pfurha ka ti-organic compounds leswi swi nga hlengeletiwa swi endliwe hi ku tirhisa nongonoko wa swivutiso leswi nga tsariwa. Ku tirhisiwe Vac-U-Chamber ku endla sampuli ya moya.

Vuyelo byi kombise leswo tihunyi ti tirhisiwa ngopfu eka makhixi kumbe switanga leswi swi nga ri ku na ku humesa kumbe ku nghenisa moya kahle ekuswekeni na ku kufumeta emitini eka ndhawu ya le makaya ya Senwabarwana. Ku tirhisiwa ngopfu tihunyu ta mixaka ya mirhi leyi landzaka eka ndhawu leyi a ku endliwa dyondzo ya ndzavisiso eka yona, ku nga, namely Mohweleri (Combretum apiculatum), Moretshe (Dichrostachys cinera), Motswiri (Combretum imberb), Mokgwa (Acacia burkei), Mushu (Acacia tortilis), Motshe (Cussonia paniculate), Mokata (Combretum hereroense), Mphata (Lonchocarpus capassa), Mokgalo (Ziziphus mucronate) and Mogwana (Grewia monticola), hi ku landzelelana hi ndlela leyi hi ku laveka ka yona mirhi leyi. Vuyelo byi tlhele byi kombisa leswo swivangelo swa ntolovelo swa khumenharhu, leswi nga na nkucetelo eka ku langa mixaka yo karhi ya mirhi ku tshovela tihunyi hi mindyangu, i swa mune: (i) malahlae yo pfurha ya ndzilo loko ku tshiveriwa, (ii) nkoka wa nkufumelo, (iii) xiyenge xa le hansi xa nkuma (iv) ku kumeka ka mixaka ya mirhi leyi leswo yi ta tshoveriwa ku va tihunyi. Nxopanxopo wo ya emahlweni vu kombise ku tirhisiwa ko hambana na ku landzelelana ka mirhi leyi ku katsa ku kambela xiyimo eka tiko hinkwaro na xiyimo eka swa nawu eka mixaka ya mirhi leyi yi nga hlayiwa laha. Ndzavisiso wa dyondzo wu kume leswo mixaka ya mirhi leyi tirhisiwaka tani hi tihunyi eka ndhawu ya le makaya ya Senwabarwana i mirhi ya ndhavuko ya ndhawu. Nsusumeto wa ku tirhisiwa ka tihunyi, exikarhi ka swin'wana, i muholo lowu kumiwaka hi ndyangu, xiyenge xa dyondzo xa vawundli va mindyangu, vukulu bya ndyangu, laha vanhu va tshamaku kona, na ku tsandzeka ku fikelela swo tshivela leswi nga duriki na leswi swi kumekeka hi ku olova.

Ku kamberiwe ku hlengeletana ka benzene, toluene, ethylbenzene, na xylene hi muxaka na muxaka wa murhi eka ndzavisiso ku endlela ku kambela vunghozi lebyi vaaki va Senwabarwana va langutaneke na byona. Ku kumeke leswo ku na hazard quotient na hazard index ku va ehansi ka ntsengo wa n'we, leswi swi kombisaka vukona bya vunghozi hi ku landza muxaka na muxaka wa murhi wa tihunyi eSenwabarwana, hambi na le ka vanhu lava nga na ntwisiso. Vunghozi bya ku va na swirhalanganyi swa rihanyu hi ku va na organic compounds eka lava a ku endliwa ndzavisiso wa dyondzo hi vona, swi nga kambiwa hi xiyenge lexi nga ri ku xa le henhla.

Marito ya nkoka: Ku thyakiseka ka moya endzeni ka yindlu; rihanyu ra mbangu; tinghozi ta rihanyu ra mbangu; Ethnobotanical phenomenology; swipimelo swa ku hlawula tihunyi;

nkambelo wa vunghozi eka rihanyu; nkambelo wa ku va eka vunghozi; tihunyi; ku tshovela tihunyi; nkambelo wa vunghozi; mixaka ya mirhi leyi tirhiseriwaku tihunyi; Volatile Organic Compounds.

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CHAPTER 1: BACKGROUND OF THE STUDY

1.1 Motivation for the Study

Access to reliable energy supply is vital for the sustainance and provision of basic human needs (Department of Energy [DoE], 2013). Different energy sources accessible to households are often classified into modern or traditional. These energy resources are thus grouped and classified into three main categories, namely (1) traditional or dirty energy sources (firewood, dung & agricultural residues), (2) intermediate energy sources (Kerosene & Charcoal) and (3) modern or clean energy sources (electricity, biogas, liquefied petroleum gas & natural gas) (World Bank, 2017).

Traditional energy sources, on the other hand are refered to as dirty energy sources, which are obtained from wood, charcoal, animal dung, straw and leaves (WHO, 2016). Firewood is one of the traditional energy sources and thus energy source of interest to the current study. It is also worth indicating that the terms energy sources and energy resources are synonymous and used interchangeably in this study. Kohler *et al*. (2009) defines energy poverty as lack of access to modern energy services. Energy services are those household services that must be provided for using available energy sources such as cooking, space heating and cooling, water heating, refrigeration and communication (radio, television, electronic mail, and the World Wide Web) (DoE, 2014). Contrary to energy sources, where modern and traditional energy sources are clarified, there is no clarification and distinction between modern and traditional energy services from accessed literature. The absence of lack of distinction between the two concepts or classification of those household services as traditional or modern energy services nullifies or invalidates the definition of energy poverty by (Kohler *et al*., 2009). The interest of this study on the above definition is its ability to categories households in the study area as being either in energy poverty or not, using valid indicators drawn from its definition.

Available literature shows that different households across the global communities use a range of mixed energy resources (World Bank, 2017). The choice of energy resources is often driven by a number of factors such as affordability, accessibility, level of education, culture, gender, marital status of household head and income, among others (Imran & Özçatalbaş, 2016; Ismail & Khembo, 2015; Dunga *et al*., 2013). Understanding the factors that influence the choices of energy sources across various communities, a question arose about the replicability or existance of unknown factors that might be behind the selction of energy sources in the current study area. Thus, this became an important research question for this study. In this context, these factors are the independent variables (X) of the study, while the energy sources are dependent variables (Y). Similarly, the relationship between the above factors and the catergories of energy sources are are also of interest in the study.

Electricity is the most globally preferred and convenient type of clean energy. However, according to Makonese *et al*., (2017) and Uhunamure *et al*., (2017) firewood also ranks high as the most commonly used and preferred type of dirty energy, mainly among non-electrified households. According to Independent Energy Access (IEA, 2018) and the World Bank (2017), 87% of the world population's households are electrified. Thus, only 1.06 billion (13%) of the global population are without electricity in their households (World Bank, 2017). The World Bank (2017) reports that 95% of the 1.06 billion people without electricity are in Asia and Africa. Although some members of the population in the Asian countries have no access to electricity, these countries are on track about the delivery of universal access to electricity by 2030. In contrast, approximately 48% of the African population remained without access to electricity as at the end of 2017, and there is no indication of when this backlog will be addressed (figure 1.1). Consequent to the lack of access to electricity, the 48% of this African households arebound to use alternative energy sources for their energy services and to sustain their daily lives.

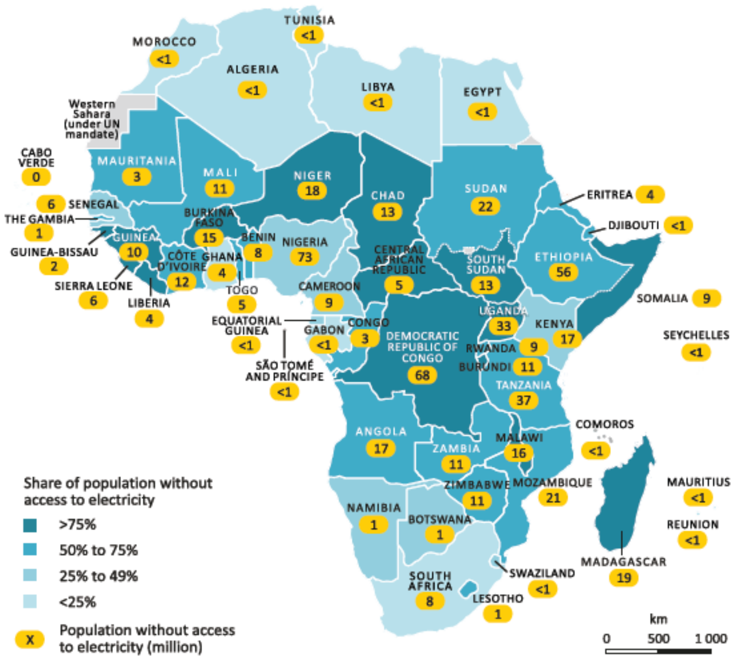

Figure 1.1 Electrification profile of African countries

Source: World Energy Outlook,2017:82.

Detailed analysis of the African electrification profile highlights that, the North African countries have mostly reached 100% average electrification rate. In contrast, the Central African countries have the lowest electrification rate at 25% in average. The rate of the East African countries' electrification is 61%, with 48% for the West African and 70% in Southern African countries. It is also evident from figure 1.2, that 13 African countries have an electrification rate of less than 25%, while, 12 African countries have an electrification rate of more than 75%. The remaining 29 African countries' electrification rates range from 26% to 74%.

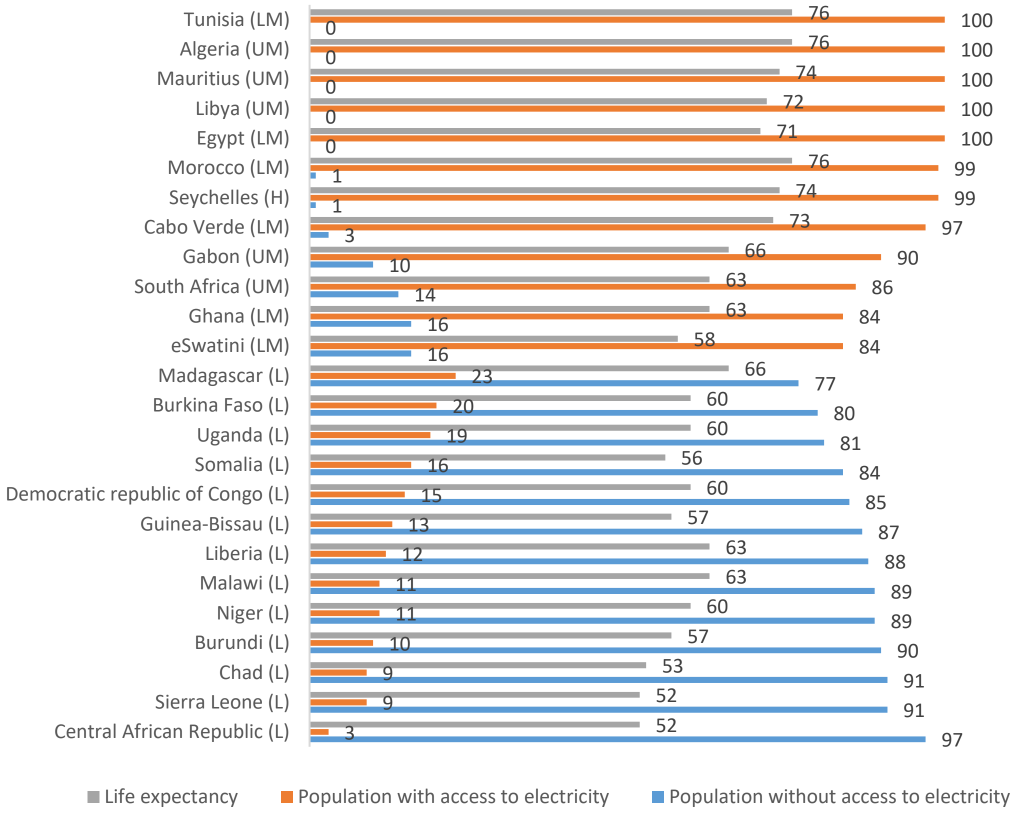

Figure 1.2 African countries with an electrification rate of less than 25% and higher than 75%

Source: International Energy Agency, 2018; World Bank, 2017.

Analysis of the three variables in figure 1.2, namely (1) electrification rate, (2) income level and (3) life expectancy confirm that there is a correlation between electrification and life expectancy. The relationship is positive, but not strong at R^2= 0,68. This observation unearths the significance of electrification as one of the interventions aimed at improving human life expectancy. It is also evident that the lower the electrification rate of households, the lower is the life expectancy. Further analysis shows an electrification range of 97% and a difference of 24 years in the life expectancy between African countries with a high rate of electrification and low rate of electrification. The averages and standard deviations of the population with access to electricity and life expectancy are 52.4 and 42.1, and 64 and 7.9 respectively. According to the United Nations World Population Prospects Revision (2015), the average life expectancy at birth worldwide was 71.5 years. The influence of electrification (access to a clean energy resource) on the longevity (life expectancy) of a society is thus an interesting question upon analysis of figure 1.2 above.

Electrification is historically meant to reduce the environmental health risks associated with indoor air pollution from household use of dirty fuels. The World Health Organisation (2018) reports that more than 3.8 million people a year die prematurely from illness attributable to the household air pollution caused by the inefficient use of solid fuels and kerosene for cooking. The sources of these deaths include stroke (34%), heart ischaemic diseases (26%), chronic obstructive pulmonary disease (22%), pneumonia (23%) and lung cancer (6%). Approximately 2000 children in South Africa die every year due to diseases related to air pollution (Scorgie *et al*., 2008). More than 50% of premature deaths among children less than 5 years of age are also due to pneumonia caused by particulate matter (soot) inhaled from household air pollution (Collins *et al*., 2013). Women and children are more exposed to indoor air pollution, and 60% of women and children die because of indoor air pollution compared to men (WHO, 2016). It is for these reasons that the current study approaches firewood use (dirty fuel) from a perspective of environmental health risk assessment.

Different communities have access to variety of plants from which firewood is harvested. The phenomenology of the firewood plant species and potential effects of the emissions thereof, remain unknown. Several previous studies that attempted to understand firewood use in rural communities did not examine the different plant species used by communities as sources of firewood (Kadafa *et al*., 2017; Langbein, 2017; Balakrishnan *et al*., 2011). These studies relied on pure laboratory experiments in which firewood from unknown tree species were used. In addition, these studies often did not investigate the variability of emissions from different types of firewood harvested from different plant or tree species, including the traditional fire making settings and dynamics. Furthermore, the focus of many studies on firewood were on individual gaseous and particulate air pollutants, with little attention if any on the volatile organic compounds (VOCs) associated with firewood burning (Kapwata *et al*., 2018; Olave, Forbes *et al*., 2017; Mitchell *et al*., 2016; Parajuli *et al*., 2016). The domestic firewood induced VOCs associated with specific firewood plant species analysis is thus one of the main focuses of the current study. Finally, the environmental health risks associated with these VOCS was examined.

1.2 Problem statement

Traditional use of firewood is projected to remain a large component of renewable energy consumption by 2030 (World Bank, 2017). However, households using firewood in open fires in poorly ventilated kitchens are subject to high levels of indoor air pollution. Air pollution is a serious environmental health threat to humans which is associated with high rates of mortality and morbidity, especially for women and children who have the greatest exposure to this pollution (Forbes *et al*., 2017; Kapwata *et al*., 2018; Makonese *et al*., 2015; WHO, 2018). Senwabarwana in Limpopo is not unique to this. Limpopo province where Senwabarwana is situated has a high electrification rate and it also has the highest rate (36%) of firewood use in the Republic of South Africa.

Interventions aimed at lowering indoor emissions of cook stoves and electrification have failed (Huboyo, 2015; Clark *et al*., 2010). Economic development normally encourages a shift from firewood and other dirty fuels to conventional fuels like oil, gas, solar and electricity but they are expensive (Sustainable Energy Agency, 2017). In a study conducted in South Africa, Madubansi and Shackleton, (2007) demonstrated that even after electrification, many households still relied on firewood and this was due to high cost of electricity.

There is a well-documented relationship between indoor air pollution and several diseases, most strongly with acute lower respiratory infections and chronic obstructive disease, lung cancer and tuberculosis. Many studies have been conducted on the monitoring of both individual gaseous pollutant (e.g. carbon monoxide, nitrogen oxides, and sulphur dioxides) as well as particulate air pollutant (Kapwata *et al*., 2018; Olave, Forbes *et al*., 2017; Mitchell *et al*., 2016; Parajuli *et al*., 2016; Joon *et al*., 2014) with little attention given to monitoring of VOCs. VOCs are carcinogenic compounds and are precursor pollutants contributing to the formation of both ground-level ozone and particulate matter (Nielsen *et al*., 2008). Exposure to volatile organic compound can induce a range of adverse human health effects. To date however VOCs exposure and residential indoor VOCs levels have not been well characterised in South Africa, less is known about health risk of exposure to VOCs from firewood.

Other problems are associated with the carrying of large bundles of wood and the distance to collect firewood. The unsustainable harvesting of indigenous trees results in the reduction or loss of many ecosystem goods and services, which only aggravate poverty (Chen *et al*., 2016). Women and children have a limited opportunity to improve their education or engage in income-generating activities because they must collect firewood (WHO, 2018).

The use of domestic firewood cannot be abandoned. It was of importance to undertake exploratory research in the Limpopo Province of South Africa, within Africa, where not many studies have been conducted previously to understand the unique factors and dynamics of the firewood use. It was therefore significant to gain an understanding of the dynamics of firewood use in electrified Bapedi households of Senwabarwana and in Africa. Firstly, it helps to close an existing literature gap; secondly, it can generate data that could help support strategies geared towards enhancing uptake of cleaner forms of energy in Senwabarwana and for other African communities using firewood.

1.3 Research question

The main research question for this study is: what the are environmental health risks associated with firewood induced volatile organic compounds (VOCs) in Senwabarwana Villages. In oder to respond to the broad research question above, the following sub-questions were investigated:

1.3.1 What are the factors that influences firewood use among electrified Bapedi households?

1.3.2 What is ethnobotanical phenomenology of firewood plants used by Bapedi households?

1.3.3 What is the concentration of volatile organic compounds in households that use different firewoods in Senwabarwana?

1.4 Chapter layout

Chapter 1: This chapter presents the rationale for the entire study, the broad research aim, objectives and the breakdown of the remaining chapters.

Chapter 2: This chapter is the conceptual framework of the study.

Chapter 3: This chapter is the methodology of the study.

Chapter 4: This chapter is an exposition of the factors associated with firewood preferences among electrified Bapedi households of Senwabarwana Villages in South Africa.

Chapter 5: This chapter presents an analysis of the ethnobotanical phenomenology of firewood plants used by Bapedi households in Senwabarwana Villages, South Africa.

Chapter 6: This chapter presents the risks associated with volatile organic compounds from combustion of household firewood.

Chapter 7: This chapter presents the summary, conclusion and recommendations of all the previous chapters.

References

Balakrishnan, K., Ramaswamy, P., Sambandam, S., Thangavel, G., Ghosh, S., Johnson, P., Mukhopadhyay, K., Venugopal, V & Thanasekaraan, V. (2011). Air pollution from household solid fuel combustion in India: an overview of exposure and health related information to inform health research priorities. *Global Health Action*, 4(1). DOI: 10.3402/gha. v4i0.5638.

Department of Energy. (2013). A survey of energy-related behaviour and perceptions in South Africa: The residential sector.

Department of Energy. (2014). Annual Report, 2013/2014. Department of Energy, Republic of South Africa.

Department of Energy. (2017). Annual report 2016-17. Accessed from http://www.energy.gov.za/files/Annual%20Reports/DoE-Annual-Report-2016-17.pdf on 30 January 2019.

Dunga, S. H., Grobler, W. & Tchereni, B. H. M. (2013). Economic Analysis of Energy Poverty in South Lunzu, Malawi. *Journal of Economics and Sustainable Development*, 4 (4).

Imran, M. & Özçatalbaş, O. (2016). The Importance of Clean and Efficient Household Energy. 2nd annual international conference on social sciences (AICSS). Yıldız Technical University - Davutpaşa Campus.

International Energy Agency. (2017). Energy Access Outlook. From Poverty to Prosperity. Access from https://www.iea.org/newsroom/news/2017/november/a-world-in-transformation-world-energy-outlook-2017.html on 15 March 2018

Ismail, Z., & Khembo, P. (2015). Determinants of energy poverty in South Africa. *Journal of Energy in Southern Africa*, 26 (3).

Joon, V., Kumar, K., Bhattacharya, M. & Chandra, A. (2014). Non-invasive measurements of carbon monoxide in rural Indian women exposed to different cooking fuel smoke. *Aerosol and Air Quality Research*, 14, 1789-1787.

Kadafa, A. A., Medugu, N. I., Stephen, D.K. & Medan J. D. (2017). The Health Impact of Fuel Wood Utilization on Users in Yelwa Village, Nasarawa State, Nigeria. *International Journal of Sciences: Basic and Applied Research*, 24 (6),174-191.

Kapwata, T., Language, B., Piketh, S. & Wright, C.Y. (2018). Variation of indoor particulate matter concentrations and association with indoor/outdoor temperature: A case study in rural Limpopo, South Africa. *Atmosphere*, 9(124).

Kohler, M., Rhodes, B. and Vermaak, C. (2009). Developing an Energy-Based Poverty Line for South Africa. *Journal of Interdisciplinary Economics*. 7(1), 127-144.

Langbein, J. (2017). Firewood, smoke and respiratory diseases in developing countries: The neglected role of outdoor cooking. *PLoS ONE*, 12(6). DOI: 10.1371/journal.pone.0178631

Makonese, T., Ifegbesan, A.P. and I. T. Rampedi. (2017). Household cooking fuel use patterns and determinants across Southern Africa: Evidence from the demographic and health survey data. *Energy & Environment*, 29 (1), 29-48.

Nielsen, E., Dybdahl, M., & Larsen, P.B. (2008). Health effects assessment of exposure to particles from wood smoke. Danish Ministry of the Environment: Environmental Protectionhttp://www.orbit.dtu.dk/.../Health_effects_assessment_of_exposure_to_particles_from_woodsmoke Accessed on19 May 2018.

Olave, R.J., Forbes, E.G.A., Johnson, C.R., & Relf, J. (2017). Particulate and gaseous emissions from different wood fuels during combustion in a small-scale biomass heating system. *Atmospheric Environment*, 157, 49–58.

Parajuli, I., Lee, H., & Shrestha, K.R. (2016). Indoor air quality and ventilation assessment of rural mountainous households of Nepal. *International Journal of Sustainable Built Environment*, 5, 301-311.

Perez-Padilla, R., Schilmann, A. & Riojas-Rodriguez, H. (2010). Respiratory health effects of indoor air pollution. *Int J Tuberc Lung Dis*, 14(9), 1079-1086.

Statistics South Africa (2018). Mid-year population estimates. Accessed from http://www.statssa.gov.za/?s=mid-year+population+estimates&sitem=publications on 15 January 2019.

Sustainable Energy Africa, University of Limpopo & City of Polokwane (2016). Household energy use and supply survey of Dikgale subdistrict of Polokwane, Limpopo. *Sustainable Energy Africa*, Cape Town.

Uhunamure, S.E., Nethengwe, N.S. & Musyoki, A. (2017). "Driving forces for fuelwood use in households in the Thulamela municipality, South Africa". Journal of Energy in Southern Africa 28 (1).

United Nations. (2018). Energy statistics pocketbook. Accessed from https://unstats.un.org/unsd/energy/pocket/2018/2018pb-web.pdf on 06 February 2019.

World Bank. (2017). State of electricity access report 2017 (Vol. 2). Washington, D.C. World Bank Group. Accessed from http://documents.worldbank.org/curated/en/364571494517675149/full-report on 11 November 2018.

World Bank. (2017). State of electricity access report 2017 (Vol. 2). Washington, D.C. World Bank Group. http://documents.worldbank.org/curated/en/364571494517675149/full-report

World Fact Book (2018). Life expectancy. Accessed from https://www.cia.gov/library/publications/the-world-factbook/rankorder/2102rank.html on 2 Febrauary 2019.

World Health Organisation. (2018). Household air pollution and health. factsheet (updated May 2018) accessed from https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health. 10 November 2018.

World Health Organisation. (2016). Burning opportunity: Clean household energy for health, sustainable, development and wellbeing of women and children. Accessed from https://www.apps.who.int/iris/bitstream/10665/204717/1/9789241565233_eng.pdf on 07 October 2018.

CHAPTER 2: CONCEPTUAL FRAMEWORK[1]

2.1 Introduction

This chapter is the conceptual framework which informed the methodology of this study. The concern resulting from the potential exposure to contaminants was the starting point to develop methodologies to evaluate the consequences that those might have on both the environment and human health. Among these methods, risk assessment has been one of the most widely used.

2.2 Risk assessment approaches

The most common risk assessment used in previous studies is termed human health risk assessment (HHRA) as applied by the following authors: (Morakinyo *et al*., 2017; Oosthuizen *et al*., 2015; Thabethe *et al*., 2014; Morandi *et al*., 2009 and Muller *et al*., 2003). According to USEPA, 2014, "Human health risk assessment" (HHRA) is defined as a complex, comprehensive and scientific method of estimating environmental-induced health risks associated with probable exposure to potential environmental hazards, as applied in the current study. The above definition resonates with various HHRA definitions provided by many other authors (The Institute of Environmental Medicine, 2018; The National Health and Medical Research Council, [NHMRC, 2008]). For example, according to the Institute of Environmental Medicine (2018), HHRA is a "multidisciplinary field of environmental health practice that is focused around the methods used to evaluate exposure [Exposure Assessment], predict health risks and outcomes [Risk Characterisation]". The National Health and Medical Research Council (NHMRC, 2008) refers to HHRA as a process of estimating [qualitative or quantitative] the "probability [likelihood or chances] that, within a certain timeframe an adverse outcome will occur in a population exposed [households] to chemical pollutants [VOCs] (in air, water, soil or food) under specific conditions" [burning of firewood].

According to USEPA 2014, risk assessment method can be either direct or indirect. The indirect method, as applied in the studies by Machete (2017); Morakinyo *et al*. (2017); Oosthuizen *et al.* (2015); Thabethe *et al*. (2014); Muller *et al*. (2003) and Habeebullah (2012) uses data from fixed monitoring stations to estimate exposure to pollutants, whereas direct

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[1] Semenya K & Machete F. (2019). Integrated Environmental Health Risk Assessment Framework for Firewood-Induced Indoor Air Pollution. *WIT Transactions on Ecology and the Environment, 236, 179-190*. DOI: 10.2495/AIR190181.

methods use biological measurements (Cattaneo *et al*., 2010). Indirect methods are more beneficial when the focus is on larger population exposure, which can be done within a shorter period and with minimal resources. Direct assessments are time-consuming and expensive; they are also not feasible for measuring more than one pollutant because of the inconvenience of attaching several samplers close to a person's breathing zone. The framework for human health risk assessment has the following four basic steps (NRC, 1993):

a) Hazard identification

Hazard identification includes a description of the specific forms of toxicity (neurotoxicity, carcinogenicity, teratogenic, etc.) that can be caused by a chemical and an evaluation of the conditions under which these forms of toxicity might appear in exposed humans (Muller *et al*., 2017; USEPA, 2014). Most studies rely on literature review for identification of hazards (Morakinyo *et al*., 2017; Muller *et al*., 2015; Oosthuizen *et al*., 2015; Thabethe *et al*., 2014;).

b) Exposure assessment

Exposure assessment is the process of finding out who is at risk, how are they exposed to a hazard, how often and how long are they exposed to the hazard, and how much of the hazard are they in contact with. Studies by Morakinyo *et al*. (2017) and Thabethe *et al*. (2014) assumed an inhalation pathway of pollutants, it is however not clear why inhalation pathway was considered over dermal and oral pathways.

c) Dose-response assessment

Dose-response assessment attempts to quantify the relationship between a particular dose and the potential adverse effect that can be caused by that dose (USEPA, 2014). Usually, dose-response assessment is based on extrapolations from data about laboratory animals, to which have been given high-doses of toxicant. In some cases, measured concentrations of pollutants from the study field are compared to the South African National Ambient Air Quality Standards (NAAQS), which serves as the benchmark (Morakinyo *et al*., 2017; Thabethe *et al*., 2014). This stage requires comprehensive screening and health data, which is often not available making it impossible to perform dose-response assessment.

d) Risk characterisation

Risk characterisation combines the information from hazard identification, exposure assessment and dose-response assessment to provide an indication of the nature and expected frequency of adverse health effects in exposed populations (Muller *et al*., 2015; Oosthuizen *et al*., 2015; Thabethe *et al*., 2014; Morakinyo *et al*., 2017). This stage can either be quantitative of qualitative.

From the definitions of EHRA and other literature analysis it emerged that there was a gap in the frameworks used, despite the large number of frameworks available. The most prominent gaps involved a lack of integration between the risk assessment frameworks and research or data collection methods employed during the studies. For example, reviewed literature indicates that some studies separate the human health risk assessment from the data collection procedure (Morikanyo *et al*., 2017; Oosthuizen *et a*l., 2015; Thabethe *et al*., 2014; Morakinyo *et al*., 2017). The methodology of these studies is separated into HHRA and monitoring phase has a data collection procedure which is not seen as part of health risk assessment.

In most instances, risk assessment studies rigorously question the validity of the data used to estimate the risks associated with an activity or operations in question. In all studies reviewed in this study, none showed concern about the quality and validity of the data collection methods and the data itself used in the study. Thus, risk assessment assumed a stand-alone process of investigation, independent from the generic research methods. This, among other gaps, left most frameworks used in previous air pollution or air quality-related studies vulnerable to myriad weaknesses. Consequently, the opportunity to improved existing human health risk assessment (HHRA) framework was identified. Thus, one of the major contributions of the current study was to improve on existing HHRA frameworks by developing the current IEHRA and ultimately applying this improved framework during the current study in Senwabarwana, both as a validation method of its feasibility.

In the current study, the risk assessment was adapted and given a new name: integrated environmental health risk assessment. This assessment was used to address the concern about the potential impact of volatile organic compounds (VOCs) on human health by examining exposure resulting from firewood combustion and the effects of such VOCs on human health. The IEHRA framework was therefore applied in Senwabarwana to assess the potential environmental health risks from VOCs formed during the combustion of firewood. The framework is discussed in detail below.

2.3 Integrated environmental health risk assessment framework.

As mentioned earlier, the IEHRA framework is an improvement on existing environmental health risk assessment frameworks. It is termed “integrated” primarily because this framework comprehensively integrates generic research methods and all their designs, tools and analysis methods into an adapted risk assessment framework. In addition to integrating generic research methods, techniques and tools, the IEHRA framework adopted various elements of existing risk assessment models that were deemed valuable.

According to Machete (2017:2), “risk” is the possibility that unwanted health and/or environmental effect will result from a particular activity or set of circumstances. In this definition, Machete (2017:2) defines “risk assessment” as a systematic process of qualitatively or quantitatively identifying, evaluating or estimating possible environmental health risks associated with environmentally induced (hazardous) activities or circumstances prevalent in a defined location or community. This definition supports the orthodox approach to risk assessment, which involves evaluating risk levels against a set of defined risk thresholds (Frazzoli et al., 2010). For the purposes of this study, environmental health risk assessment is a systematic process of quantifying and/or qualifying (including estimating) firewood-induced human health risks resulting from VOCs. For this purpose, the IEHRA process gathered all relevant data, identified hazards (firewood-induced VOCs) and analysed (and estimated) the exposure complexities and their associated human health risks, in line with Paustenbach (2000).

Thus, the current risk assessment framework integrates all three types of risk assessment, namely baseline, issue-based and continuous, into one framework. This kind of risk assessment approach is consistent with the environmental risk assessment framework adopted by the Department of Environmental Affairs and Tourism (2002a, 2002b). Each of the three risk assessment approaches serves different purposes and is based on its definitional elements. Baseline risk assessment is commonly the first type of risk assessment conducted to generate a baseline risk profile for an environment or activity. The second type of risk assessment (i.e. issue-based) focuses on a specific issue or activity. The primary purpose of issue-based risk assessment in the current study was to analyse hazards, levels of exposure and risks associated with the demographic profile, location, geophysical features, infrastructure (kitchen) and operations of the domestic environment where firewood is used (Department of Environmental Affairs and Tourism, 2002b). Lastly, continuous risk assessment was confined in this study to an analysis of risks associated with the daily operations of the domestic rural kitchens

(Department of Environmental Affairs and Tourism, 2002b). Clearly, each type of risk assessment is focus-based, and that issue-based risk assessment builds on the baseline risk assessment.

The IEHRA framework for firewood-induced environmental health risks was customised and considered other existing risk assessment frameworks, such as the human health risk assessment (Muller *et al*., 2003; Thabethe *et al*., 2014; Oosthuizen *et al*., 2015; Morakinyo *et al*., 2017; Machete, 2017). Consequently, a three-pillar IEHRA was adapted based on Machete (2017), building on existing frameworks (figure 2.1).

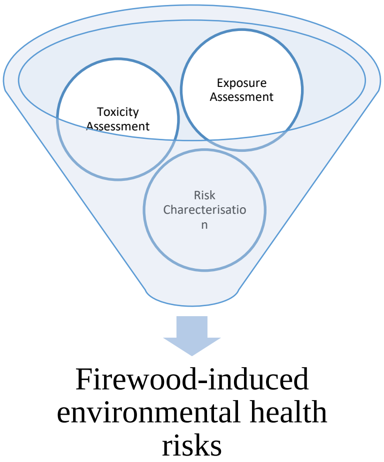


Figure 2.1 integrated environmental health risk assessment framework

The three components of the IEHRA framework in figure 2.1 are discussed in detail below:

2.3.1. Toxicity assessment

Toxicity assessment is the first step of environmental risk assessment, which integrates hazard identification and dose-response assessment (Machete, 2017). This assessment concerns the agent or hazard and its adverse effects, as well as the correlation of the dose and the response thereof. It uses various kinds of studies, such as epidemiological, biological, physiological and toxicological, to identify and assess hazards. It also establishes the relationship between the dose and the extent of an adverse response (Paustenbach, 2000). Four study designs and approaches were adopted at this stage of the IEHRA (see figure 2.2).

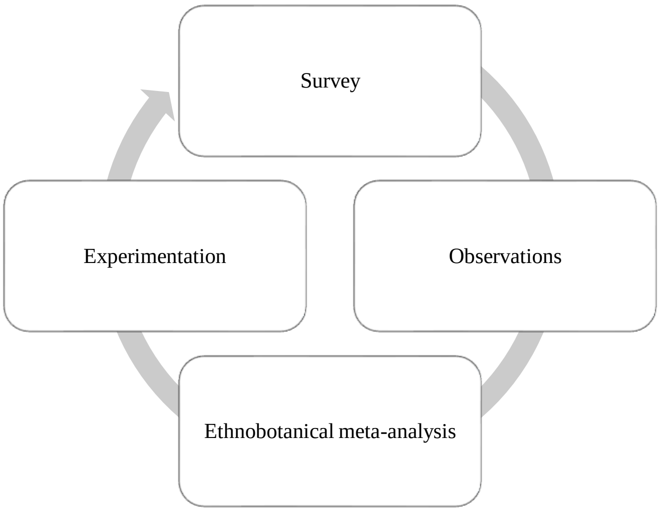


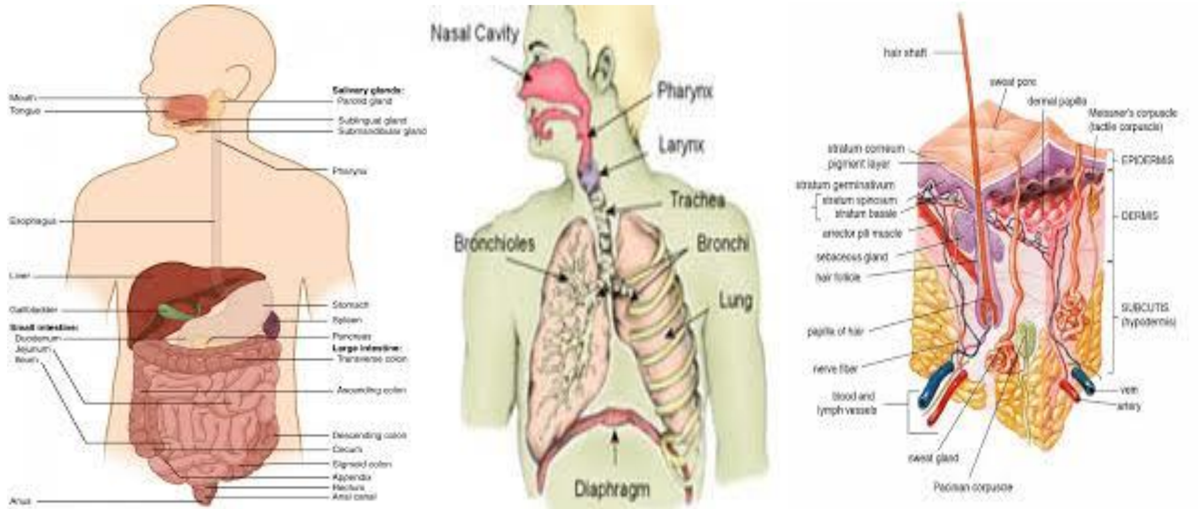
Figure 2.2 Toxicity assessment framework

In this study, surveys were conducted by means of structured interviews to assess and analyse the circumstances in which firewood was used in the study area. The survey also served as the groundwork for hazard identification. As discussed earlier, and in response to the gaps identified in previous studies on air pollution, the current research identified and analysed the different types of trees from which households harvested their firewood. Through descriptive statistical analysis and frequency analysis, priority tree species were identified.

The priority tree species were named in the local language (Sepedi), since the interviews were also conducted in both English and Sepedi, depending on the preferences of the respondents. The use of two languages in conducting the interviews allowed the respondents to express themselves freely and to give the different names of trees in their home language. However, this language posed the challenge of confirming the tree names between the common or botanical names of the identified trees with those ethnobotanical names. To overcome this challenge, this first part of the IEHRA used observation designs to sample specific wood species from the different households and photographs of these trees were taken. In addition, the study sourced the botanical characteristics of each listed tree species, which resulted in a field trip with willing community members to identify these trees in the nearest field. This highlighted the current IEHRA's attention to detail when compared with the existing frameworks.

2.3.2. Exposure assessment

The focus of exposure assessment is to determine existing and/or anticipated human exposure, potential human exposure pathways, as well as exposure levels from the hazards identified in the earlier stage of this IEHRA (Frazzoli et al., 2010). Exposure assessment is a key component of risk assessment, despite its being fraught with uncertainties because of the myriad dynamics involved, such as the exposure rate, duration of exposure, contact agent, location of the agent, its exact availability and other factors (Paustenbach, 2000). In terms of the human health risk assessment framework, exposure assessment often involves epidemiological, biological, physiological and toxicological studies (Janis, 2001). In human beings, exposure to toxins occurs through three major routes, namely inhalation (lungs), dermal (skin) and oral (mouth) (Machete, 2017). Primarily, these three exposure routes constitute three human anatomical and physiological systems, namely the respiratory, integumentary and digestive systems (see figure 2.3).



Human digestive system

Human respiratory system

Human integumentary system

Figure 2.3 Human anatomy and physiological systems or routes of entry for VOCs

Source: TeachPE. (2018)

By understanding these three human anatomical and physiological systems, it is clear that human exposure to firewood-induced VOCs can occur through direct and/or indirect methods. Consequently, the measurement methods for direct and indirect exposure involve physiologically based pharmacokinetic (PB-PK) modelling and environmental sampling, respectively (Paustenbach, 2000). For the direct measurement method, the primary focus is on measuring the concentration of substances by taking a specimen or sample from the environment or human body. However, the indirect measurement method involves measuring the concentration levels of an agent or hazards (VOC emissions from firewood combustion) outside the human body. Indirect measurement methods are known as ambient or environmental monitoring or measurement. For the purposes on this study, the indirect measurement methods are referred to as “environmental measurement methods”. The current study adopted the indirect measurement methods because, according to Machete (2017), indirect measurement methods assume that ambient substances are readily available for absorption into the exposed human body through the three human anatomical and physiological systems, including through secondary exposure to the surrounding environmental features, such as water, air, land, animate and inanimate.

To assess potential human exposure to firewood-induced VOCs comprehensively, the current study used numerous data from two of the four study designs discussed earlier (observation & experimentation). From the survey (structured interviews), there were specifically designed questions that were aimed at assessing the exposure complexities of households. Examples included questions about the frequency of fire making per day, different uses of the fire in a household to estimate the exposure routes and potential high-risk individuals in a family. During the observation phase, the researcher assessed the physical structure of the kitchen designs, the floor area (size) of the kitchen in relation to the family size, the number of windows or vents and their ratio to the floor area and the potential for cross-ventilation, among other things. Lastly, through experimentation, the burning of different wood species within defined standards and the collection of indoor emissions enabled the researcher to simulate the potential emissions that can be inhaled and enter the human body through the different routes of exposure. The results of the experimental study thus represent the estimation of what firewood users could be exposed to.

All the survey, observation and experimental data were analysed through descriptive and inferential statistical methods to extrapolate the statistical meanings of these findings. Different variables were classified and coded according to their hypothesised relations to other variables. Thus, final analyses were based on the relationships that were the subject of the exposure investigation (Machete & Shale, 2016). These multivariable were in various forms or types of data, such as ordinal, nominal and interval data, as defined by Keller (2014). Ultimately, the inference that was drawn from this component of second stage of the IEHRA was that there is a probability of human exposure to firewood-induced VOCs, given the limitations and strengths of the methods of indirectly measuring VOCs and other data sources, such as the survey and observations

2.3.3. Risk characterisation

As alluded to and defined earlier, IEHRA is a process of gathering data and making assumptions to estimate the nature, severity and likelihood of harm to the environment (including human health). Therefore, risk characterisation is the last step of the IEHRA process and summarises all data from the previous two IEHRA stages or steps (Caravanos *et al*., 2013). In addition, risk characterisation is the stage of IEHRA at which conclusions are drawn, based on the strengths, weight and limitations of the evidence or available data about the environmental hazards resulting from domestic firewood use (Janis, 2001; Slack *et al*., 2005). However, risk characterisation relies on the quality of the data and information about the potency of the effect caused by the environmental hazards, population affected, types of environmental health effects, the likelihood of exposure and public concerns over the issue in question (Jung *et al*., 2005; Yong-Chul *et al*., 2005). Thus, this three-step IEHRA was adopted as the research method for this study (see figure 2.4).

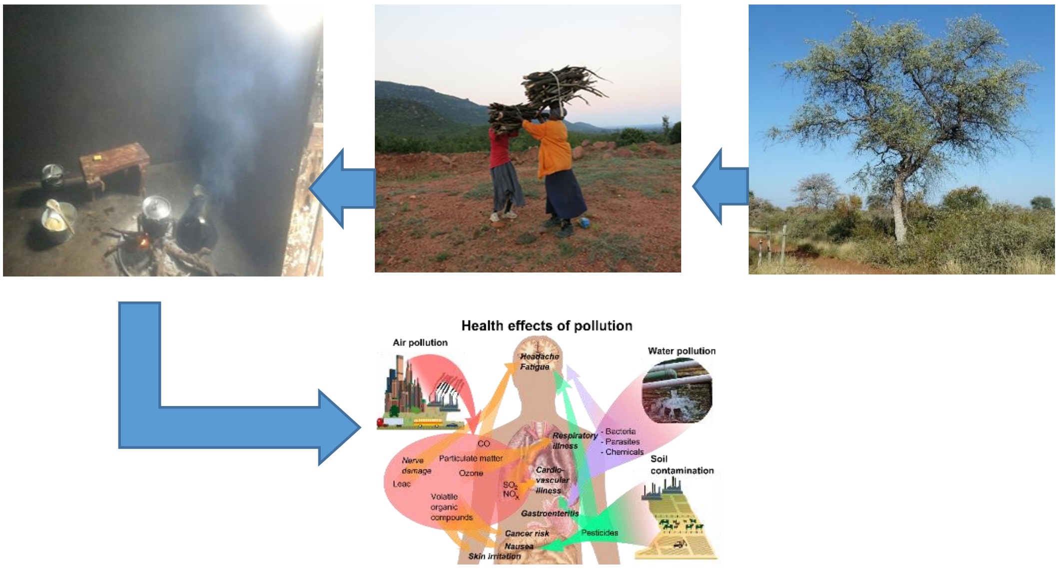


Figure 2.4 Risk characterisation framework followed in the study

Depending on the nature of data and analysis methods followed, risk characterisation can be qualitative, quantitative and/or a mixed method. Quantitative risk characterisation involves the use of arithmetic to determine the risk levels and compare such levels with a certain matrix. On the other hand, qualitative risk characterisation involves subjective explanatory analysis of the findings of the previous two IEHRA stages. The third and last risk characterisation method involves a combination of both qualitative and quantitative methods. The mixed method was the method adopted in this study. The mixed method of risk characterisation involved the collection, analysis and use of qualitative and quantitative methods interchangeably, as was found to be relevant in each of the three stages of risk assessment. Ultimately, it yielded a comprehensive understanding and contextualisation of the real environmental health and dynamics that households are potentially experiencing daily.

2.4 Conclusion

This chapter reviewed existing air pollution-related risk assessment frameworks. The aim of the chapter was to examine the best environmental health risk assessment framework with the intention of adopting the most suitable one – or adapting one for the current study area. During such reviews, it emerged that there was a large gap in both the frameworks and the methods used, despite the large number of frameworks and research methods available. The most prominent gaps involved a lack of integration between the risk assessment frameworks and generic research methods employed during the studies. This, among other gaps discussed earlier, left most methods and frameworks used in previous air pollution or air quality-related studies vulnerable to myriad weaknesses, as also discussed earlier. Consequently, the opportunity to develop an improved and integrated environmental health risk assessment (IEHRA) framework was identified. Thus, one of the major contributions of the current study was to improve on existing EHRA frameworks by developing the current IEHRA and ultimately conducting the study in the Senwabarwana Villages, using this improved framework.

References

Agency for Toxic Substance and Disease Registry. (2007). The toxic guide. Accessed from https://www.atsdr.cdc.gov/substances/toxsubstance.asp?toxid=14 on 3 October 2018.

Alcaraz, X. (2013). Assessing workplace IH hazards using qualitative risk assessment. Environmental Health Safety and Sustainability Consulting. Accessed from www.allianceoccmed.com/.../Qualitative_Risk_Assessment_Methods_042513_XAlcar on 9 October 2018.

Azuma, K., Uchiyama, I., Uchiyama, S. & Kunugita, N. (2016). Assessment of inhalation exposure to indoor air pollutants: Screening for health risks of multiple pollutants in Japanese dwellings. *Environmental Research*, 145, 39-49.

Batterman, S., Su, F-C., Li, S., Mukherjee, B. & Jia, C. (2014). Personal exposure to mixtures of volatile organic compounds: Modeling and further analysis of the RIOPA data. Research report 181. MA Health Effects Institute, Boston.

Caravanos, J., Kevin, C., Bret, E., Landrigan, P. J. & Fuller, R. (2013). The burden of disease from pediatric lead exposure at hazardous waste sites. *Environmental Research*, 120, 119-125

Carrer, P., Trantallidi, M., Dimitroulopoulou, S., Efthimiou, G., Sakellaris, I., Bartzis, J. & Wolkoff, P. (2013). WP7-Exposure and health risk assessment: Report on the health risk associated with emissions from household use of selected consumer products. Executive Agency for Health and Consumers- EAHC. Framework of the health programmes 2006-2013. European Union.

Cheng, Z., Li, B., Yu, W., Wang, H., Zhang, T. & Bu, Z. (2017). Risk assessment of inhalation exposure to VOCs in dwellings in Chongqing, China. Healthy buildings 2017 Europe. ISBN: 978-83-7947-232-1.

Cox, L.A. (2008). What's wrong with risk matrices? Risk Analysis, 28, (2). DOI:10.1111/j.1539-6924.2008. 01030.x

Creswell, J.W. (2014). Research design: Qualitative, quantitative and mixed methods approaches. 4th ed. SAGE Publications, Inc.

Creswell, J. W., Hanson, W. E., Clark, V. L. P. & Morales, A. (2009). Qualitative research designs: selection and implementation. *The Counselling Psychologis*, 35, 236-264.

Dai, H., Jing, S., Wang, H., Ma, Y., Li, L., Song, W. & Kan, H. (2017). VOC characteristics and inhalation health risks in newly renovated residences in Shanghai, China. *Science of the Total Environment*, 577, 73-83.

Department of Health. (2018). Guideline for the management of indoor air quality: A guide for environmental health practitioners in South Africa. Pretoria: South Africa.

Department of Environmental Affairs and Tourism. (2002a). Ecological Risk Assessment, Integrated Environmental management. Pretoria.

Department of Environmental Affairs and Tourism. (2002b). Impact Significance, Integrated Environmental management. Pretoria.

Department of Water Affairs and Forestry. (1998). Minimum Requirements for Handling, Classification and Disposal of Hazardous Waste. Pretoria: Depart of Water Affairs and Forestry.

Díez, H.E. & Pérez, J.F. (2017). Physicochemical characterization of representative firewood species used for cooking in some Colombian regions. *International Journal of Chemical Engineering*. DOI:10.1155/2017/4531686.

De Winter, B., De Winter, M. & Killick, D.J.B. (1966). Sixty-six Transvaal trees. Botanical Research Institute, Department of Agricultural Technical Services. Pretoria.

European Chemicals Agency. (2012). Practical Guide 15. How to undertake a qualitative human health assessment and document it in a chemical safety report. Accessed from https://echa.europa.eu/documents/.../pg_15_qualitative-human_health_assessment_do. on 9 October 2018.

Evtyugina, M., Alves, C.A., Calvo, T., Nunes, L., Tarelho, M., D. & Prozil, S.O. (2013). Emission of volatile organic compounds from the residential combustion of Pyrenean oak and black poplar. *International Journal of Environmental and Ecological Engineering*, 7(6).

Frazzoli, C., Orisakwe, O. E., Dragone, R. & Mantovani, A. (2010). Diagnostic health risk assessment of electronic waste on the general population in developing countries’ scenarios. *Environmental Impact Assessment Review*,30, 388-399.

Gawrys, M., Fastyn, P., Gawlowski, J., Gierczak, T. & Niedzielski, J. (2001). Prevention of water vapour adsorption by carbon molecular sieves in sampling humid gases. *Journal of chromatography A*, 933, 107-16.

Gratt, L.B. (1996). Air toxic risk assessment and management: Public health risks for normal operations. Van Nostrand Reinhold, USA.

Hopkins, D., & Williams, D. (2011). Guidance on human health risk assessment for environmental impact assessment in Alberta. Edmonton, Alberta: Health Protection Branch, Alberta Health & Wellness. Accessed from https://open.alberta.ca/publications/guidance-on-human-health-risk-assessment-for-environmental-impact-assessment-in-alberta on 8 October 2018.

Inkoom, D.K.B. & Crentsil, A.O. (2015). Estimation of indoor air pollution and health impacts due to biomass burning in rural northern Ghana, in case studies for developing globally responsible engineers, GDEE (eds.), Global dimension in engineering education, Barcelona. Accessed from http://gdee.eu/index.php/resources.html on 5 October 2018.

Institute of Environmental Medicine. (2018). Environmental health risk assessment. Accessed from https://ki.se/en/imm/environmental-health-risk-assessment on 5 October 2018.

Janis, S. (2001). Landfill sites. Risk of adverse birth outcomes. Practice Nurse 1 66.

Jones, D. (1992). Nomenclature for hazard and risk assessment in the process industries. Rugby, Warwickshire, UK: Institution of Chemical Engineers.

Joon, V., Kumar, K., Bhattacharya, M. & Chandra, A. (2014). Non-invasive measurements of carbon monoxide in rural Indian women exposed to different cooking fuel smoke. *Aerosol and Air Quality Research*, 14, 1789-1787.

Kapwata, T., Language, B., Piketh, S. & Wright, C.Y. (2018). Variation of indoor particulate matter concentrations and association with indoor/outdoor temperature: A case study in rural Limpopo, South Africa. *Atmosphere*, 9, 124. DOI: 10.3390/atmos9040124.

Kothari, C.R. (1990). Research methodology, methods and techniques. 2nd ed. New Delhi: Prakashan.

Machete, F. (2017). Environmental health risks associated with e-waste exposure in Badplaas, Carolina and Elukwatini landfills, Republic of South Africa. *African Journal of Science, Technology, Innovation and Development.* DOI: 10.1080/20421338.2017.1355602

Machete, F. & Shale, K. (2015). Classification of unregulated landfills by waste stream analysis method, a case of Chief Albert Luthuli Municipality, South Africa. *African Journal of Science, Technology, Innovation and Development*, 7 (6): 446-452.

Mitchell, E.J.S., Lea-Langton, A.R., Jones, J.M., Williams, A., Layden, P. & Johnson, R. (2016). The impact of fuel properties on the emissions from the combustion of biomass and other solid fuels in a fixed bed domestic stove. *Fuel Processing Technology*, 142, 115-123.

Morakinyo, O. M., Adebowale, A.S., Mokgobu, M.I. & Mukhola, M.S. (2017). Health risk of inhalation exposure to sub-10µm particulate matter and gaseous pollutants in an urban-industrial area in South Africa: An ecological study. BMJ Open. DOI: 10.1136/bmjopen-2016-013941.

Mouton, M. (2001). How to Succeed in your Masters and Doctoral Studies. Pretoria: Van Schaik Publishers.

Muller, E., Diab, R.D., Binedell, M. & Hounsome, R. (2015). Health risk assessment of kerosene usage in an informal settlement in Durban, South Africa. *Atmospheric Environments*, 37, 2015-2022.

Naeher, L.P., Brauer, M., Lipsett, M., Zelikoff, J.T., Simpson, C.D., Koenig, J.Q. & Smith, K, R. (2007). Woodsmoke health effects: A review. *Inhalation Toxicology*, 19, 67-106.

Nassiuma, D.K. (2000). Survey sampling: Theory and methods. Nairobi: Nairobi University Press.

National Health and Medical Research Council (NHMRC). (2008). Guidelines for managing risk in recreational water. Canberra: Commonwealth of Australia.

Nielsen, E., Dybdahl, M. & Larsen, P.B. (2008). Health effects assessment of exposure to particles from wood smoke. Danish Ministry of the Environment: Environmental Protection Agency. Accessed from http://www.orbit.dtu.dk/.../Health_effects_assessment_of_exposure_to_particles_from_wood smoke on 4 March 2018.

Nolte, C.G., Schauer, J.J., Cass, G.R. & Simoneit, B.R.T. (2001). High polar organic compounds present in wood smoke and in the ambient atmosphere. *Environmental Science Technology*, 35, 1912-1919.

Northern Health. (2015). Guidance on human health risk assessment. Accessed from https://www.northernhealth.ca/...health/...health.../documents/guidance-human-health- on 7 October 2018.

Obernberger, I., Brunner, T. & Barnthaler, G. (2006). Chemical properties of solid biofuels – significance and impact. *Biomass and Bioenergy*, 30, 973-982.

Olave, R.J., Forbes, E.G.A., Johnson, C.R. & Relf, J. (2017). Particulate and gaseous emissions from different wood fuels during combustion in a small-scale biomass heating system. *Atmospheric Environment*, 157, 49-58.

Oosthuizen, M.A., Wright, C.Y., Matooane, M. & Phala, N. (2015). Human health risk assessment of airborne metals to a potentially exposed community: A screening exercise. *The Clean Air Journal*, 25(1), 51-57.

Parajuli, I., Lee, H. & Shrestha, K.R. (2016). Indoor air quality and ventilation assessment of rural mountainous households of Nepal. *International Journal of Sustainable Built Environment*, 5, 301-311.

Paustenbach, D.J. (1989). The risk assessment of environmental and human health hazards: A textbook of case studies. John Wiley & Sons, USA.

Pie, S.J. (1991). Mountain culture and forest management of Himalayas. *Himalayan Ecosystem*, 114-120.

Plejdrup, M.S., Nielsen, O. & Brandt, J. (2016). Spatial emission modelling for residential wood combustion in Denmark. *Atmospheric Environment*, 144, 389-396.

Ramos, M.A. & De Albuquerque, U.P. (2012). The domestic use of firewood in rural communities of the Caatinga: How seasonality interferes with patterns of firewood collection. *Biomass & Bioenergy*, 39, 147-158.

Scientific Kit Cooperation. (2018a). Application guide (Sampling train-air sample bags). Accessed from http://www.skcltd.com on 14 February 2018.

Scientific Kit Cooperation. (2018b). Step-by-step guide (An introduction to air sampling). Accessed from http://www.skcltd.com on 14 February 2018.

Smith, K. (2013). Environmental hazards: Assessing risk and reducing disaster. 6th ed. Abingdon, Oxon; New York: Routledge.

Smith, K.R. (1984). Air pollutant emissions, concentrations and exposures from biomass combustion: The cigarette analogy. Paper presented at the Annual Meeting of the American Chemical Society, Division of Fuel Chemistry, Philadelphia, PA.

Tabuti, J.R.S., Dhillion, S.S. & Lye, K.A. (2003). Firewood use in Bulamogi County, Uganda: Species selection, harvesting and consumption patterns. *Biomass & Bioenergy*, 25, 581-596.

Thabethe, N.D.L., Engelbrecht, J.C., Wright, C.Y. & Oosthuizen, M.A. (2014). Human health risks posed by exposure to PM10 for four life stages in low socio-economic community in South Africa. *PanAfrican Medical Journal*, 18(206). doi:10.11604/pamj.2014.18.206.3393.

The National Academic Press. (2018). Toxicity testing. Accessed from https://www.nap.edu/read/11523/chapter/3 on 5 October 2018.

The respiratory system (Teachpe). (2018). Accessed from https://www.teachpe.com/anatomy-physiology/the-respiratory-system-breathing/the-respiratory-system on 5 November 2018.

Thomas, V. & Grant, R. (2011). Sappi tree spotting: Highlands, Highveld, Drakensberg, Eastern Cape Mountains. Jacana Media, Johannesburg: South Africa.

Ullah, S. & Bibi, S. (2018). Ethnobotanical survey of medicinal plants of Musamina District Malakand Khyber Puthtoonkhwa, Pakistan. *Academia Journal of Medicinal Plants*, 6(6), 122-126.

United States Environmental Protection Agency. (2014). Framework for human health risk assessment to inform decision-making. Accessed from https://www.epa.gov/sites/production/files/2014-12/.../hhra-framework-final-2014.pdf on 15 May 2018.

Van Wyk, B.E. (2002). A review of ethnobotanical research in Southern Africa. *South African Journal of Botany*, 68, 1-13.

Venter, F. & Venter, J. (1996). Making the most of indigenous trees. Briza Publications, Pretoria: South Africa.

Wang, H., Lou, S., Huang, C., Qiao, L, Tang, X., Chen, C., Zeng, L., Wang, Q., Min Zhou, M., Lu, S. & Yu, X. (2014). Source profiles of volatile organic compounds from biomass burning in Yangtze River Delta, China. *Aerosol and Air Quality Research*, 14, 818–828.

Williams, A., Jones, J.M., Ma, L. & Pourkashanian, M. (2012). Pollutants from the combustion of solid biomass fuels. *Progress in Energy and Combustion Science*, 38, 113-137.

World Health Organisation. (2018). Household air pollution fact sheet. Accessed from http://www.who.int/en/news-room/fact-sheets/detail/household-air-pollution-and-health on 5 September 2018.

Wright, C. (2009). Air pollution monitoring and evaluation framework for South Africa: Prioritizing vulnerable communities. *WIT Transactions on Biomedicine and Health*, 14. doi:10.2495/EHR090061.

Yang, Y.B., Ryu, C., Khor, A., Yates, N.E., Sharifi, V.N.& Swithenbank, J. (2005). Effect of fuel properties on biomass combustion. Part II. Modelling approach – identification of the controlling factors. *Fuel*, 84, 2116-2130.

CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter presents integrated environmental health risk assessment (IEHRA) framework as applied in Senwabarwana Villages. The IEHRA framework consists of three stages, namely toxicity assessment, exposure assessment and risk characterisation. Each of these stages incorporates different generic research methods, such as surveys, observations and experimentation. This integrated framework balances the limitations of different methods (including study designs, tools and methods of data analysis) with the strengths of different stages of risk assessment, and vice versa. Finally, the IEHRA, which includes both a risk assessment framework and generic research methods, makes the IEHRA a multifaceted framework and a specialised risk-oriented research method and technique.

3.2 Toxicity assessment

This is the first step of the framework in which the study area and the tools used to conduct the study are discussed. The population is discussed under toxicity assessment.

3.2.1 Study area

This study was conducted in Senwabarwana. Senwabarwana is the primary node of the Blouberg municipality which is situated within the borders of Botswana and Zimbabwe (Figure 3.1). It is approximately 93 km northwest of the Polokwane city.

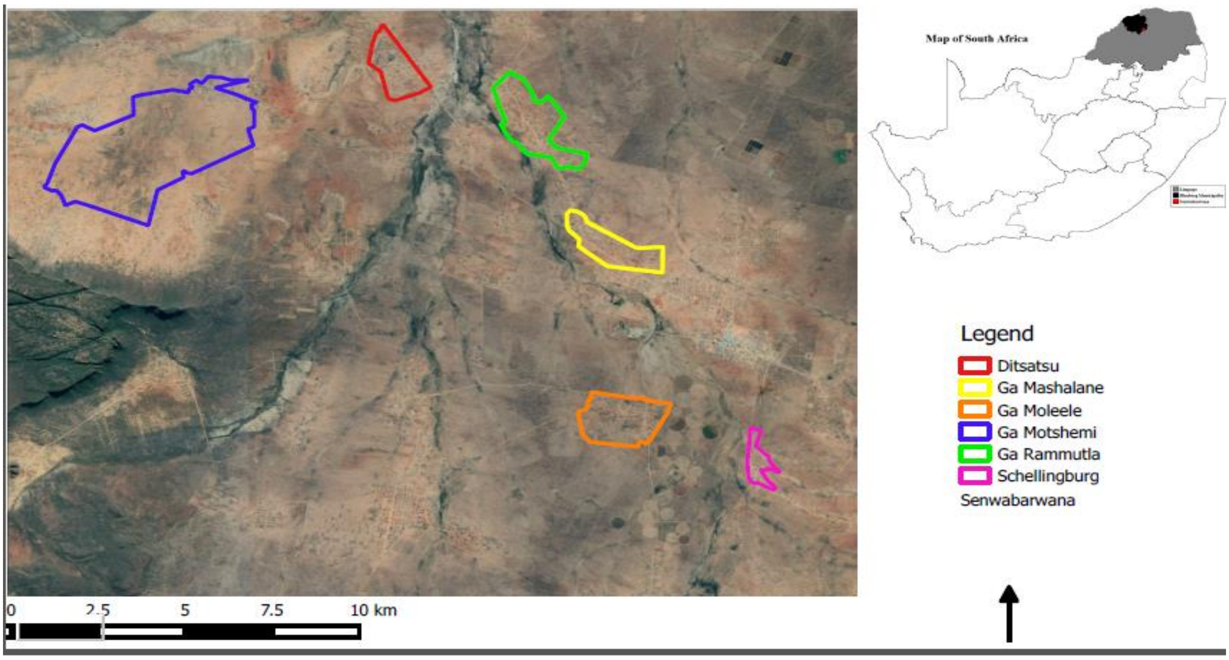


Figure 3.1 Senwabarwana Map

(*source: department of geography UNISA*)

According to Blouberg Local Municipality annual report (2018), Senwabarwana has 2300 households with a population of 10 000. The Senwabarwana Villages are situated very close to one another and the following villages formed part of this study: Ga-motshemi, Ga mashalane, Ditatsu, Schellingburg, Ga moleele, Ga Rammutla.

The area has lot of various mountains with the Blouberg Mountain being the biggest mountain; Makgabeng Mountain is the national heritage site. The municipality is divided into three categories of land ownership; land owned by private individuals that consists mainly of farms that are used for agricultural purposes, land owned by traditional leaders where large communities reside, live, and state land. The area is rich in flora and fauna, which needs to be preserved for current and future generations. However, high levels of poverty and lack of knowledge about environmental preservation have rendered the area prone to many environmental challenges, since most people rely on natural resources such as wood, soil, plant and animal life for their survival.

There are also high levels of unemployment and illiteracy in this area. Many households survive on an annual income of less than R18 000, making it difficult to afford basic needs such as electricity. Most families depend on government social grants. About 97% of households in this municipality are connected to the electricity grid, but many families use firewood daily for their energy requirements. According to the Department of Energy (DoE, 2016), when compared with the other provinces in South Africa, Limpopo has the highest number (35%) of households using firewood.

According to Blouberg Local Municipality (2018), all the residential areas within the municipality are connected to the electricity grid. The electrification of extension areas is currently underway. Hananwa, which is the area on top of the Blouberg Mountains, is using solar energy. The municipality has started with the installation of high mast lights in areas of Senwabarwana, Letswatla, Taaibosch, and Inveraan. In Alldays the solar powered streetlights project is complete and functions efficiently. 97 % of households have access to electricity.

3.2.2 Sampling

Sampling is the process of selecting a portion of the population to represent the entire population and is used to draw inferences about that population (Polit & Hungler, 1999). Exploratory design, according to Brink and Wood (1998), calls for small samples that are chosen through deliberative process to represent the desired population. In qualitative research individuals are selected to participate in the research based on their first-hand experience of the phenomenon of interest. Unlike quantitative research, there is no need to randomly select individuals because manipulation, control and generalization of findings are not the intentions of the study (Streubert & Carpenter, 2003). Due to the large number of households in the study area and limited resources, it was impossible to sample all the households. Therefore, a non-probability sampling was used for this study followed by convenience sampling selecting accessible respondents. The researcher further used the purposive sampling method. This method was used because the researcher was interested in respondents who are knowledgeable and experienced with firewood making processes and trees used as firewood. According to Bless and Smith (1995) purposive sampling is based on the judgement of a researcher regarding the characteristics of a representative sample. 69 households are therefore the number of households that were found to fit the profile of the study. The households were identified fom the following villages: GaMotshemi (10), GaMashalane (10), Ditsatsu (9), Schellingburg (15), GaMoleele (10), GaRammutla (15). The household heads of these families were interviewed and provided response on behalf of all family members of the households.

3.2.3 Study design

The study used a mixed method study design composed of three stages. The first stage was the interview and questionnaire administration, the second stage was observation, collection of firewood and identification of firewood, while the third stage was lab experimentation. According to Burns and Grove (2003), the design of a study is the result of a series of decisions made by the researcher concerning how the study will be conducted. The design is closely associated with the framework for implementing the study. Research designs vary about how much flexibility is allowed once the study is underway (Polit & Hungler, 1995). The selection of research design depends on the nature of the problem being investigated and the purpose of the study (Cresswell, 2014). This study is descriptive in nature. Newman (2000) emphasise that descriptive research presents a picture of the specific details of a situation, social setting or relationship. The descriptive method of a research is used to gather information about the present existing condition concerning the status of the subject of the study (Creswell, 2014). Jackson (2009), noted that descriptive study determines and reports the way things are and commonly involves assessing attitude, opinions towards individuals, organizations and procedures. Data was collected from residents. Data collection methods used included the questionnaires, interviews, direct observation and literature review.

3.2.4 Data collection tools

This study used mixed methods data collection strategies. Mixed method data collection strategies are those that are designed to combine elements of one method with elements of the other in either a sequential or simultaneous manner (Axinn & Pearce, 2006). Varying the data application approaches reduces non-sampling error by providing redundant information from multiple sources and ensures that a potential bias coming from one particular approach is not replicated in alternative approaches (Creswell, 2013).

Using different sources of information gathering is also referred to as triangulation and it helps in minimising biases coming from the use of a single method (Howell et al., 2005). The researcher conducted an empirical research that is both quantitative and qualitative methods, which presented original research findings (Mouton, 2001). The selection of mixed method helped the researcher to gain special opportunities to the use of multiple sources of information from multiple approaches to gain new insights into firewood use in Senwabarwana.

a) *Qualitative method*

According to De Vos *et al*. (2002) the qualitative research paradigm, in its broadest sense, refers to research that elicits participation accounts of meaning, experience or perceptions. It produces descriptive data in the participant's own written or spoken words. A qualitative study is concerned with non-statistical methods and small purposively selected samples. Polit and Hungler (1999) maintain that a qualitative method is especially useful for exploring the full nature of little-understood phenomenon. Bless and Higson-Smith (2006) provides a closely related definition by referring to it as the set of procedures that guide the researcher in the process of verifying a particular hypothesis and excluding all other possible hypotheses or explanations. This study is qualitative in the sense that it aimed to explore the real situation concerning firewood use in Senwabarwana. The qualitative research involved an action method. An action research is described as a research method that is collaborative and participatory, focusing on a practical problem experienced by participants for whom a practical solution is sought (Maree, 2008). The action research is qualitative because it strongly focuses on understanding the problem and is explicitly committed to the empowerment of the participants and will in the end contribute to changing their current situation (Mouton, 2001). The rationale for using qualitative approach was to explore firewood use in Senwabarwana.

b) *Quantitative method*

Mouton and Marais (1996), define quantitative research as the approach used by researchers in the social sciences that is more formalised in nature than qualitative research, as well as explicitly controlled, with a more carefully defined scope. Quantitative research is a formal, objective, rigorous and systematic process for generating information about the phenomenon (Burns & Grove, 2003). Evidence for a quantitative study is gathered according to a specific plan in which formal instruments are used to collect the needed information.

This information is translated into numeric information and analysed using statistical procedures (Polit & Hungler, 1995). The advantage of quantitative method is that the measurements are valid, reliable and can be generalised with clear anticipation of cause and effect (Creswell, 2013). This method helped the researcher to prevent bias in gathering and presenting research data. This research type was non-experimental since it only aimed at describing the situation at hand without being manipulative (Maree, 2008).

3.2.5 Questionnaires

These were aimed at obtaining information on major aspects on firewood use which, included types of wood used (tree species); area where wood is obtained (Distance), the socio demographics, cooking activities (cooking duration per day per meal). According to Ho et al. (2016), it is important to collect necessary information about the monitoring site with a questionnaire prior to monitoring.

a) *Development of a questionnaire*

The use of previous studies provided useful information for research on contemporary problems related to firewood use (Axinn & Pearce, 2006). Bryman and Bell (2007) confirms that the use of secondary data offers the prospect of having access to good quality information with very little resources used in the process. The literature review helped in guiding the researcher on issues worth analysing and the development of the questionnaire used in this study.

b) *Mode of Administration*

A semi-structured questionnaire with closed and open-ended questions was used in this study (Annexure 1). These were aimed at obtaining information from the household head on major aspects on firewood use which, included types of wood used (tree species); area where wood is obtained (Distance), the socio demographics, cooking activities (cooking duration per day per meal). Bryman and Bell (2007) noted that the use of closed questions lead to: ease of processing answers; enhanced comparability of answers; easier to show relationship between variables; easier to make comparisons between variables and easier to make comparisons between respondents. These are easy to analyse statistically but they limit the respondent's response (Jackson, 2009). Open ended questions lead to a greater variety of responses from participants but are difficult to analyse statistically because the data must be reduced in some manner. The questions were formulated to understand household use of firewood, areas where firewood is collected, different types of plants used as firewood (Annexure 1).

Creswell (2014) finds self-administered questionnaires to be cheaper as compared to other modes of administration and having an advantage or reaching a large sample size, cover wide geographical area and excellent for capturing sensitive topics. The questionnaires may be mailed or sent to the participants electronically. However, this method has some challenges such as questionnaires returning incomplete and/or unanswered, and some questionnaire returning late. For this study in person-administration of the questionnaire was adopted. The questionnaires were administered by a group of four well trained students. Even though it is an expensive method, it has an advantage of interacting with the participants (Mouton, 2001). This helped in clarifying the questions especially in cases where the participants were illiterate.

The researcher made several visits to Senwabarwana, taking note of firewood making processes. Observation to capture qualitative information such as the delivery methods of collected wood, storage area, harvesting tools, kitchen characteristics, building height, floor area, roof type, wall material, stove type, ventilation (number and size of windows, doors and chimney). The information collected was then used in conjunction with the quantitative data. During this process, photographs were taken. Each sample of identified wood species was collected for further analysis in the laboratory.

3.2.6 Observation and checklist

The researcher made several visits to Senwabarwana, taking note of firewood making processes. Observation checklist was used to capture qualitative information such as the delivery methods of collected wood, storage area, fire making process; harvesting tools, kitchen characteristics, building height, floor area, roof type, wall material, stove type, ventilation (number and size of windows, doors and chimney). The information collected was then used in conjunction with the quantitative data. During this process, photographs were taken. Each sample of identified wood species was collected for further analysis in the laboratory.

3.2.7 Secondary data

The use of previous studies provided useful information for research on contemporary problems related to firewood use (Axinn & Pearce, 2006). Bryman and Bell (2007) confirms that the use of secondary data offers the prospect of having access to good quality information with very little resources used in the process.

Following Cresswell (2009) and Leedy and Ormrod (2015), qualitative and quantitative data (secondary and primary) data from literature sources and structured interviews were used to determine the common uses of firewood in general, globally and among the electrified Bapedi households within Senwabarwana Villages.
Secondary data sources were randomly selected through online search, using content analysis method. Subsequently, selected range of key words, based on their frequency of appearance from the in-depth literature analysis were used to determine relevance of a secondary source for inclusion in the study. The literature review helped in guiding the researcher on issues worth analysing and the development of the field observation questionnaire used in this study (Annexure 1).

3.3 Data analysis

Data analysis involves reducing the volume of raw information, sifting it and identifying patterns and trends that reveals the true meaning of what was contained in the data (De Vos, 2005). Mouton (2001) refers to analysis as consisting of three concurrent flows of activity, namely: data reduction, data display and conclusion drawing.

Data reduction refers to the process of selecting, simplifying and transforming data that appear in the original documents. As with data reduction, the creation and use of display is not separate from analysis but part of it. The third activity in analysis is conclusion drawing and verification. According to this view, qualitative data analysis is a continuous process. Data was captured and analysed with Microsoft Excel. Different data analysis techniques were employed: ranging from simple descriptive statistics such as mean, variance, percentages, frequencies and cross tabulations presented in the form of charts, tables and figures to inferential statistical tests.

3.3.1 Ethnobotanical meta-analysis

In-depth reviews and meta-analysis of the identified plant species was used to align the descriptive features of each identified plants with their common, botanical and scientific names. This analysis also helped this study to identify other different ethnobotanical uses of these plants, the number of uses each plant has and the potential relations such uses have in the legislative or plant status in South Africa.

In conducting this multi-analysis of primary data, authoritative sources such as national legislation were given the priority, previous South African studies received second priority, frequency of publications identifying a plant species by a particular name and years of publication of such studies were ranked the least, respectively (figure 3.2).

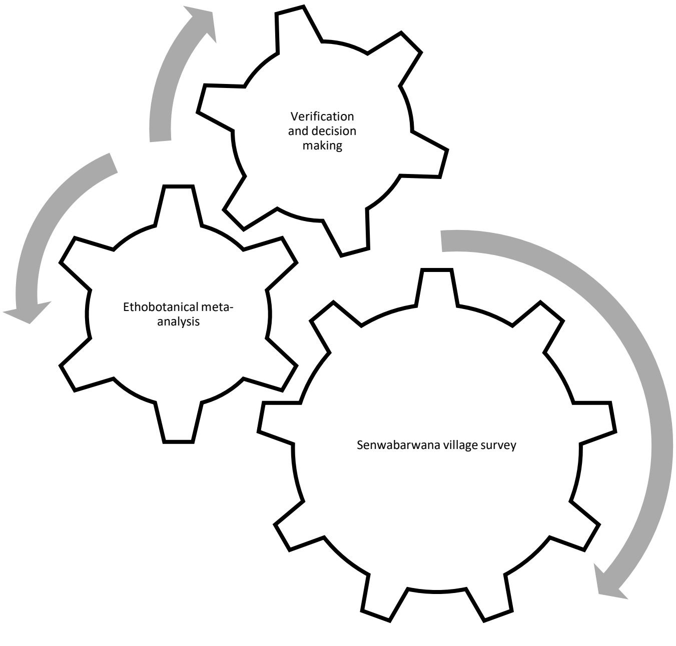


Figure 3.2 Ethnobotanical phenomenology framework

Each of the three steps produced specific outputs to the current study, namely (1) survey produced names of plant species in the local language (Sepedi) identified by the Senwabarwana Village as the trees that they use for firewood, (2) step two produced the common and botanical names of different ethnobotanical identified tree species, including contradictions in the classification, and (3) produced the final verified and final list and descriptions of ethnobotanical plant species used for firewood at Senwabarwana. Step two of the methodology also added the ethnobotanical knowledge of other uses of these plant species, in addition to their use for firewood which was the primary focus of the current study. Thus, step three used, among others this knowledge in its verification and decision-making process. This step (the ethnobotanical meta-analysis) is the main difference between human health risk assessment and integrated environmental health risk assessment.

3.4 Validity and reliability of the questionnaire

Reliability is explained as the extent to which a tool can be relied upon to give the results that are consistent (Howell et al., 2005). Similar results must be obtained if the same test is carried out on more than one occasion under similar conditions (Maree, 2008). While reliability is concerned with the accuracy of the measuring instrument or procedure, validity is concerned with the study's success at measuring what the researcher set out to measure. Validity refers to how well a questionnaire can measure what it is intended to measure (Howell *et al.*, 2005). To validate the effectiveness of the questionnaire the researcher conducted a pilot study in which seven participants were sampled form the study area. All the seven partcipants understood the questions and were able to complete the questionnaire within 20 minutes. Some questions were however amended after realising ambiguity of certain statements.

3.5 Experimentation

The experimentation and the steps involved are discussed in detail below:

3.5.1 Sample preparation and laboratory setup

The five most used tree species Mohweleri (*Combretum apiculatum*), Moretshe (*Dichrostachys cinera*), Motswiri (*Combretum imberbe*), Mokgwa (*Acacia burkei*) and Mushu (*Acacia tortilis*) were tested in the experimental phase. Many factors affect the fuel performance in combustion, including the heat value index, heat potential, durability of embers, elemental composition, physical properties (e.g. density, size), ash residue and availability of oxygen; therefore, these should all be taken into consideration when combusting woody fuel. Since this study took place in a laboratory setup simulating the Senwabarwana kitchen these factors were assumed to be constant.

The wood was intended for residential heating and cooking and had been air-dried by the residents. The wood was cut into equal-sized logs prior to combustion. The combustion methods were designed to reflect the Senwabarwana kitchen and stove setup of cooking, using a tripod open-fire method. A laboratory room of 4.5 m2 floor area; 2.4 m floor-to-ceiling height; two windows opposite each other on the sides on the room and a door with the fire area on the centre of the room. The Vac-U-Chamber was placed at a level equivalent to the breathing zone of an individual engaged in cooking (0.5 –1 m above the floor and 0.5–1 m from the source). Air samples were collected before the start of the fire and during combustion from ignition. This was done to get accurate measurements.

3.5.2 Sampling of pollutants

The Vac-U-Chamber (Size: Large- 483 x 356 x 198 mm) from SKC was used to sample the air. Vac-U-Chamber is equipped with three quarter inch fitting ports (inlet port, purge port and vacuum port) for inflating the sample bag. Inlet port connects to the sample line, purge port purges the air when preparing the bag for a standard, while vacuum port inflates the bag. Air sample bag was connected to the inside sample inlet port and the chamber was closed to provide an airtight seal.

An air sample pump was connected to the outside vacuum outlet port. The pump was activated to evacuates air from inside the chamber. The sample bag inflated because of the interior pressure drop. This technique allowed the air sample to enter the bag directly without passing through the pump, protecting the pump from sample contaminants and the sample from pump contaminants.

The sampling period was 1 hour, which is equivalent to the cooking period as indicated by Senwabarwana residents depending on what is being cooked. The bag was filled to less than 80% of its maximum volume in accordance with the manufacturer's instructions. For accurate measurements, three replicate tests were performed for each wood species. Air monitoring over a five-day period in spring (September 2018) were considered adequate since assessment considered acute rather than chronic exposure (USEPA, 1996).

3.5.3 Description of the sampling bag

This study used 1-litre Teflon Tedlar bags to sample a volume of air. These bags are simple to use, inexpensive, reusable and available in various sizes, normally from 500 ml to 1 litre. This method enables the measurement of short-term exposure for many substances (sampling duration of a few minutes). A disadvantage of using Tedlar bags is that compounds may not remain stable for more than 24–48 hours (Woolfenden, 2010). Some bags are also permeable to certain chemicals, so losses of significant amounts of sample have been observed when they have been stored for prolonged periods. To avoid this, samples were taken to the laboratory immediately after sampling. Moreover, Tedlar bags can allow humidity to diffuse when relative humidity levels differ between the inside and the outside (Gawrys et al., 2001). As a result, a double-layer Tedlar bag has been designed with a drying agent between the two films to limit the impact of external humidity on a low-humidity sample (SKC, 2018).

3.5.4 Sample storage and analysis

The samples for this study were sent to the SKC Safety Health and Environment South African laboratory immediately after sampling as per handling suggested by SKC (2018). The samples were marked to indicate numbers, date collected and tree species to avoid discrepancies and for accuracy. The VOC bags were analysed at an accredited laboratory (SKC South Africa Chemtech Laboratory, accreditation number T0361) using the NIOSH 2549 analytical method.

3.6 Exposure assessment

It was assumed that the breathing zone concentration is equal to the near-field concentration (USEPA, 2014). Since the focus of this study is on acute exposure, the following equation was used to estimate exposure concentration (USEPA, 2009):

$$EC = CA \qquad (1)$$

Where: EC (µg/m3) = exposure concentration.

CA (µg/m3) = contaminant concentration in air.

According to USEPA (2009) for acute exposures, the EC is equal to the CA. EC was then used as the dose the population of Senwabarwana may be exposed to per chemical or pollutant when inhaling wood smoke. According to Guo *et al*., (2003), inhalation exposure to air pollutants is the most significant pathway compared to other exposure pathways therefore exposure though other routes can be ignored.

3.7 Risk characterisation

The risk caused by exposure to firewood BTEX among the Senwabarwana population was characterised using the hazard quotients (HQ) for the inhalation pathway. The following formula was used (USEPA, 2009):

$$HQ = EC/(\text{Toxicity Value}) \qquad (2)$$

Where: HQ (unitless) = Hazard Quotient.

EC (µg/m^3) = exposure concentration.

Toxicity Value (µg/m^3) = Inhalation toxicity value (e.g., Reference Concentration (RfC) or Reference Exposure Level (REL) that is appropriate for the exposure scenario (acute, subchronic, or chronic).

Toxicity value is the concentration that the population of Senwabarwana may be exposed to without suffering negative health risks (USEPA 2009). The following Guidelines were used to interpret HQ calculations (Lemly, 1996; Muller *et al*., 2003; Thabethe *et al*., 2014):

HQ = <0.1, no hazard exists
HQ = 0.1–1.0, hazard is low
HQ = 1.1–10, hazard is moderate
HQ = >10, hazard is high

Since exposure to these chemicals occurs concurrently, the combined effects of exposure, hazard index (HI) was calculated using the following formula (USEPA, 2009):

$$HI = HQbenzene + HQtoluene + HQethylbenzene + HQxylene \qquad (3)$$

HI < 1 no risk

HI > 1 potential adverse effects, increases as the HI value increases.

3.8 Ethical Consideration

According to Mouton (2001), scientific research is a form of human conduct and must therefore adhere to certain values and norms. This study involved human participants and addressed ethical issues such as privacy and safety of participants as well as the safety of the researcher, consent and confidentiality of the participants. A well-informed consent explaining the aim and purpose of the study was attached to each questionnaire; this was to ensure that the participants understands their role in the study and understand that their participation was voluntarily. The participants were also informed that they may withdraw from the study at any time, should they wish to do so. The participants were made aware that the research is an academic requirement and any information gathered will be treated with strict confidentiality, including their identities.

The confidentiality of the participants was maintained by not disclosing their names and personal information in the study. Since this addressed the four principles of research: no harm to participants; informed consent; invasion of privacy and no deception was involved (Bryman & Bell, 2003). The project received ethical clearance from the College of Agricultural and Environmental Sciences (CAES) ethics committee at the University of South Africa (UNISA).

3.9 Limitation of the study

Due to financial constraints the sample size was a small proportion of the entire population. Research studies with larger sample size would be required to ensure appropriate generalisation of the study. The effects from a single or short-term exposure can differ markedly from effects resulting from repeated or long-term exposures. The BTEX monitoring was conducted over a short period and as such no indication of seasonal fluctuations in pollutants could be obtained and the long-term health risks could not be estimated. Future studies should be conducted over a longer period that would allow an estimate of the risk of cancer effects and should include the assessment of the risk posed by exposure to other pollutants.

The response to the chemical by the exposed person depends upon factors such as whether the chemical accumulates in the body, whether it overwhelms the body's mechanisms of detoxification or elimination, or whether it produces irreversible effects. The health effects arising from dermal contact or ingestion of BTEX from firewood combustion was also not covered by this study. It is therefore recommended that further direct epidemiological studies be conducted in this area to determine the concentrations of BTEX in Senwabarwana community.

Despite the indicated limitations the study was able to assess the risks associated with BTEX from firewood combustion.

References

ATSDR (Agency for Toxic Substance and Disease Registry). (2007). The toxic guide. Accessed from https://www.atsdr.cdc.gov/substances/toxsubstance.asp?toxid=14. On 3 October 2018.

ATSDR (Agency for Toxic Substance and Disease Registry). (2018). Minimal risk levels. Accessed from https://www.atsdr.cdc.gov/mrls/pdfs/atsdr_mrls.pdf. on 5 October 2018.

Axinn, W.G. & Pearce, L.D. (2006). Mixed Methods Data Collection Strategies. New York, Cambridge University Press.

Bless, C. & Higson-Smith, C. (2006). Fundamentals of Social Research Methods: An African Perspective. 4th Ed. Cape Town: South Africa.

Blouberg Local Municipality. (2018). Draft Integrated Development Plan 2018/2019-2021. Accessed from https://www.blouberg.gov.za/idp. on 5 March 2018.

Brink, P.J. & Wood. M.J. (1998). Advanced Design in Nursing Research. Sage Publications.

Bryman, A. & Bell, E. (2007). Business Research Methods. New York: Oxford University.

Burns, N. & Grove, S. K. (2003). Understanding nursing research. 3rd Ed. Philadelphia: WB. Saunders Company.

Creswell, J.W. (2008). Educational research: Planning, conducting, and evaluating quantitative and qualitative research.3rd Ed. Upper Saddle River, NJ: Pearson Education.

Creswell, J.W. (2009). Qualitative Research Introduction. Educational Research: Planning, Conducting and Evaluating Quantitative and Qualitative Research. 3rd Ed. Upper Saddle River, NJ. Pearson, Education.

Creswell, J.W. (2012). Educational Research: Planning, Conducting and Evaluating Quantitative and Qualitative Research. 4th Ed. Upper Saddle River, NJ. Pearson, Education.

Creswell, J.W. (2014). Research Design: Qualitative, Quantitative and Mixed methods approach. 4th ed. Thousand Oaks, California: SAGE Publications.

Department of Energy. (2016). Annual report 2016-17. Accessed from http://www.energy.gov.za/files/Annual%20Reports/DoE-Annual-Report-2016-17.pdf. on 30 January 2019.

De Vos, A., S., Strydom, H., Fouche, C. B.& Delport, C.S.L. (2005). Research at grass roots. For the social sciences and human service professions. Pretoria, Van Schail Publishers.

Guo, H., Lee, S.C., Chan, L.Y., & Li, W.M. (2003). Risk assessment of exposure to volatile organic compounds in different indoor environments. *Environmental Research*, 94, 57–66.

Howell, J., Miller, P.H.H., Sattler, D., Schack, T., Sprey, E., Widhalm, S. & Palmquist, M. (2005). Reliability and Validity. Accessed from http://www.writing.colostate.edu/guides/research. on 15 January 2017.

Jackson, S.L. (2009). Research Methods and Statistics: A critical Thinking Approach. 3rd Ed. Belmont.

Leedy, P, D. & Ormord, J, E. (2015). Practical Research: Planning and design. 11th Ed. Boston.

Lemly, A.D. (1996). Evaluation of the hazard quotient method for risk assessment of selenium. *Ecotoxicology and Environmental Safety*, 35(2), 156–-162.

Maree, K. (2008). First steps in Research. Pretoria; Van Schaik Publishers.

Mouton, M. (2001). How to Succeed in your Masters and Doctoral Studies. Pretoria: Van Schaik Publishers.

Mouton, J. & Marais, H.C. (1996). Basic concepts in the Methodology of the Social Sciences. Revised edition. Pretoria: Human Sciences Research Council.

Muller, E., Diab, R.D., Binedell, M. & Hounsome, R. (2003). Health risk assessment of kerosene usage in an informal settlement in Durban, South Africa. *Atmospheric Environment,* 37, 2015–2022.

Newman, W.L. (2000). Social Research Methods: Qualitative and Quantitative Approaches. Massachusetts: Allyn & Bacon.

Polit, D.F. & Hungler, B.P. (1987). Nursing Research: Principles and Methods. 3rd Ed. Pennysylvania: Lippincott.

Scientific Kit Cooperation (SKC). (2018). Step by step guide (An introduction to air sampling) Accessed from http://www.skcltd.com. 10 November 2017.

Streubert-Speziale, H.J. & Carpenter, D.R. (2003). Research in Nursing: Advancing the Humanistic Imperative. 3rd Ed. New York.

Thabethe, N.D.L., Engelbrecht, J.C., Wright, C.Y. & Oosthuizen, M.A. (2014). Human health risks posed by exposure to PM10 for four life stages in a low socio-economic community in South Africa. *Pan African Medical Journal*, 18 (206).

USEPA (United States Environmental Protection Agency). (2009). Risk Assessment Guidance for Superfund (RAGS); Volume, I: Human Health Evaluation Manual; Part F, Supplemental Guidance for Inhalation Risk Assessment: Final; USEPA: Washington, DC, USA. Accessed from https://www.epa.gov/sites/production/files/2015-09/documents/partf_200901_final.pdf. On 26 September 2018

USEPA (United States Environmental Protection Agency). (2014). Framework for Human Health Risk Assessment to Inform Decision Making. Accessed from https://www.epa.gov/sites/production/files/2014-12/.../hhra-framework-final-2014.pdf. On 26 September 2018.

USEPA (United States Environmental Protection Agency). (2018). Indoor Air Quality. Technical overview of Volatile Organic Compounds. Accessed from: https://www.epa.gov/indoor-air-quality-iaq/technical-overview-volatile-organic-compounds. on 26 September 2018.

Woolfenden, E. (2010). Sorbent-based sampling methods for volatile and semi-volatile organic compounds in air—part 1: sorbent-based air monitoring options. *Journal of Chromatography A*, 1217(16), 2674–2684.

CHAPTER 4: FACTORS ASSOCIATED WITH FIREWOOD PREFERENCES[2]

4.1 Introduction

Firewood remains a primary energy resource among electrified South African households, in rural communities (Uhunamure *et al*., 2017). According to Makonese *et al*. (2018), firewood is the preferred energy resource for cooking and heating in most southern African countries such as Angola, Lesotho, Malawi, Namibia, Swaziland, Zambia and Zimbabwe. Firewood is a historically well-known primary energy resource used for space heating and cooking. In the twenty-first century, the available literature still attributes firewood uses to many communities (World Bank, 2012; Nyankone & Waithera, 2016). The World Bank (2012) estimates that 40% of the global population still relies on traditional or biomass fuels such as firewood, straws and cow dung for cooking.

In 2012, the International Energy Agency (IEA, 2012) estimated the number of households that rely on solid fuels would increase to 2.7 billion by 2030 if energy use does not change. In contrast, the World Health Organisation (WHO, 2016) confirmed in 2016 that more than 2.9 billion families in the world are still using solid fuels such as animal dung, coal, plant waste and wood for cooking and space heating. The WHO (2016), revealed that 95% of solid fuel dependent populations are in sub-Saharan Africa. The use and dominance of firewood as one of the main biomass or solid fuels in households is associated with several known and unknown factors. One of the common, known factors is energy poverty and lack of access to alternative or clean energy such as electricity. This is supported by the World Bank (2012), which reported that 20% of the global population did not have access to electricity in 2012.

A study by Ezzati and Kammen (2001) found that 96% of the population in Kenya does not have access to electricity and consequently more than 80% of the population relies on solid fuels. A 2016 report by the South African National Department of Environmental Affairs (DEA, 2016) attributed the use of firewood to lack of access to and unaffordable costs of electricity in rural and urban households. In contrast, a study conducted in Ga-Dikgale village

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[2] Semenya K and Machete F. (2019). Factors that influence firewood use among electrified Bapedi households of Senwabarwana Villages, South Africa. *African Journal of Science, Technology, Innovation and Development*. DOI.10.1080/20421338.2019.1572336.

in Limpopo, South Africa, found that some households in the province still use solid fuels for cooking and heating, despite being connected to electricity grid (City of Polokwane *et al.*, 2016). This study revealed that some households use firewood as an alternative energy resource when they run out of electricity and animal dung, firewood, paraffin and gas are the most common alternatives for cooking, space and water heating in Ga-Dikgale Village in Limpopo (City of Polokwane *et al.*, 2016).

Previous studies have presented several reasons why households use different forms of energy. However, there is no consistency in their findings. A case in point is a study conducted in Ga-Dikgale Limpopo in 2016 where the use of firewood was still prevalent, even though houses were electrified (City of Polokwane *et al.*, 2016). Some studies suggest that several rural households cannot afford modern fuels such as liquefied petroleum gas (LPG) or electricity; hence, they resort to firewood and dung. In support of the above, the South African National Department of Energy (DoE, 2013 and Díez & Pérez, 2017) concluded that most rural households are poor and rely on firewood and animal dung because these two materials are readily available and accessible. According to Makonese *et al*. (2015) the electricity price increases by an estimated 25% annually in South Africa, making it highly expensive for low-income households. As a result, people continue to rely on dirty solid fuels such as firewood and animal dung.

A study by Al-Subaiee (2016) found that firewood is the prime source of energy in Saudi Arabia. Nyankone and Waithera (2016) confirmed that firewood is the most popular source of energy in Kenya. In Sudan, solid fuels such as firewood, charcoal, crop residues, straws and dung are the primary source of cooking energy (Suliman, 2013). Abdul-Hakim and Ibrahim (2017) concluded that a higher percentage of households in Kano, a northern metropolis in Nigeria, use firewood compared to other fuels. The researchers found that while 55% of households in Kano have access to electricity, 66.3% of households rely mainly on firewood (Abdul-Hakim & Ibrahim, 2017). The results of a Nigerian study conducted by Buba *et al*. (2017) concluded that 76% of the sampled households largely depend on solid fuels, while 72% of the respondents reported they use firewood more than other energy sources for cooking. A similar trend was observed in Tanzania where 81.8% of respondents relied on firewood (Ifegbesan *et al*., 2016).

While reliance on polluting cooking fuels varies widely from region to region in Africa, South East Asia and the Western Pacific region have by far the highest proportions of households primarily using polluting fuels for cooking (WHO, 2016). According to City of Polokwane *et al*. (2016), the reliance of communities on dirty fuels like firewood is attributed to their lack of finance to buy cleaner energy sources such as electricity. In support of view Chen *et al*. (2016) reported that biomass is the most accessible and affordable fuel in rural China. Díez and Pérez (2017) found the high percentage of poverty in Cordoba state in the Caribbean region drives nearly half the rural population to use solid fuels. DEA (2016) in South Africa blames the lack of electricity in rural areas and its high cost in the cities for keeping the poor dependent on solid fuels.

The World Bank (2012) is concerned about the negative impact of the use of firewood on women and children. According to the WHO (2016), more than 98,000 of women die in Nigeria every year due to firewood use in households. The problem is firewood is often burned in enclosed rooms that are poorly ventilated, and the emission of smoke decreases indoor air quality. Black soot from the smoke is often deposited on the inside walls of rooms or kitchens where fires are commonly made. Both the smoke and the soot contain toxic pollutants (Smith, 2000), which have the potential to harm those who are exposed to them. Individuals who live near or cook on fires are most at risk.

According to Duflo *et al*. (2008), indoor air pollution caused using dirty solid fuel is a major public health problem globally and a threat to users. The WHO (2016) warns that a person who cooks three times a day on firewood is exposed to smoke, which is equivalent to smoking 20 packets of cigarette a day. Accordingly, WHO (2016) points out that rural women and children carried on the women's backs are the most vulnerable to inhaling toxic air pollutants from firewood. Globally, more than four million people die prematurely annually due to respiratory diseases caused by inhalation of pollutants from firewood combustion (WHO, 2016).

Furthermore, a study by the IEA (2010) shows that combustion of firewood in households release greenhouse gases (GHGs) into the atmosphere which contribute to climate change and global warming. The IEA (2010) associates firewood emission of GHGs with the incomplete combustion process that takes place during fire making at household levels. Another environmental challenge associated with household reliance on firewood is that trees are harvested without replanting, which results in a net addition of heat-trapping carbon to the atmosphere (Bailis *et al*., 2015). The consequence of increased heat-trapping carbon in the atmosphere is deforestation and the disruption of the ecosystem. Thus, this paper presents the factors that influence firewood use among electrified Bapedi households in Senwabarwana.

4.2 Materials and Methods

This chapter is based on survey (structured interviews) as a primary data collection method and meta-analysis (in-depth exploratory and explanatory analysis of 70 authoritative secondary data sources) to conceptualise and formulate research variables which were investigated in this study. These secondary data sources were randomly selected through online search (google, google scholar and UNISA Library), using content analysis method. Subsequently, selected range of key words (such as: firewood; firewood dependency; socio-economic dynamics in relation to firewood use; energy poverty; source of energy), based on their frequency appearance from the in-depth literature analysis were used to determine relevance of a secondary source for inclusion in this paper. Following Cresswell (2009) and Leedy and Ormrod (2010), qualitative and quantitative data (secondary and primary) data from literature sources and structured interviews were used to determine the common uses of firewood in general, globally and among the electrified Bapedi households within Senwabarwana Villages, including. The analysis included the identification and prioritisation of factors that influence firewood use in these households. An explanatory research approach adopted from Creswell (2012) was used. Data analyses were descriptive and presented through qualitative figures and table in accordance with Keller (2014). Semi-quantitative analysis of the drivers of firewood use among selected communities (Creswell 2009) was performed.

4.3 Results and Discussion

4.3.1 Common types of energy used in selected communities

Table 4.1 presents a breakdown of common energy resources in selected countries of the world based on meta-analysis results.

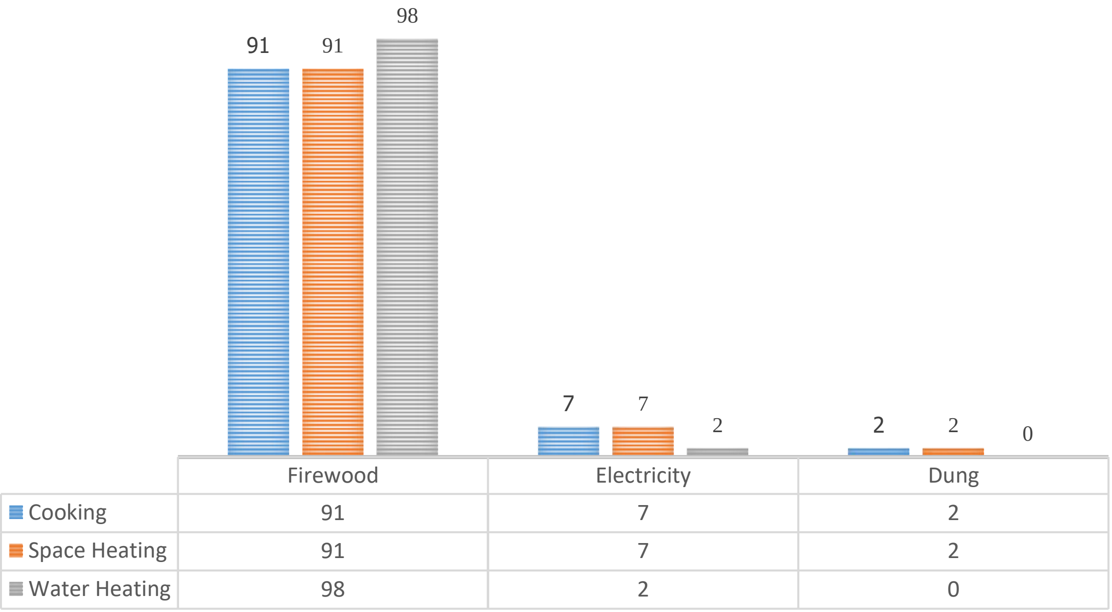
Table 4.1 Different types of energy used in different communities

Study area	**Fuel type**							**Author**
	Firewood	*Electricity*	*Dung*	*Biogas*	*LPG*	*Charcoal*	*Kerosene*	
China	1		1	1			1	Chen *et al*., 2016.
South Africa	1	1						Uhunamure *et al*., 2017
Pakistan	1	1			1			Moeen *et al*.,2016
Nigeria	1						1	Maurice *et al*., 2015
Saudi Arabia	1	1						Al-Subaiee, 2015
Sudan	1	1					1	Suliman, 2013
Kenya	1	1		1			1	Nyankone &Waithera, 2016
Nigeria	1	1		1	1	1	1	Buba *et al*. 2017
Nigeria	1				1		1	Abdul-Hakim & Ibrahim2017
India	1	1	1		1		1	Hanna & Oliva, 2015
Tanzania	1	1			1	1	1	Massawe *et al*., 2015
Nigeria	1						1	Ebe, 2014
Nigeria	1	1			1		1	Ogwumike *et al*., 2014
United states of America		1			1		1	USEIA, 2015
Latin America		1			1			IADB, 2017
Britain		1			1			Advani *et al*., 2013
Colombian regions	1				1		1	Díez & Pérez, 2017
Tajikistan: Western Pamirs	1		1			1		Mislimshoeva *et al*., 2014
Ghana							1	Karima *et al*., 2016
Zimbabwe	1							Remigios, 2014
Southern Africa	1	1			1	1		Makonese *et al*., 2017
Nigeria	1	1			1	1	1	Ifegbesan *et al*., 2016
South Asia	1	1			1		1	Rahut *et al*., 2014
Northern Cameroon	1	1					1	Nlom & Karimov, 2015
Nigeria	1				1	1	1	Ado *et al*.,2016
Malawi	1							Timko & Kozak, 2016
South Africa	1	1						City of Polokwane *et al*.,2016
Total	23	17	3	3	14	6	17	

From table 4.1, it is evident that firewood is an energy resource of choice selected by 85% of households in 27 study areas, followed by electricity and kerosene at 63%. Liquefied petroleum gas is used by 52%, charcoal by 22.2%, while dung and biogas are used by only 11.1% of the households in the 27 study areas, respectively. This analysis demonstrates the extent to which communities still rely on dirty fuels like firewood, regardless of the negative impact it has on environmental health. Clearly, the use of firewood is not about to end soon. Given the importance of firewood as an alternative energy resource for households and the challenges associated with its use, this study sought to review factors that influence firewood use in electrified households.

4.3.2 Reasons for selected energy preferences by households

In the structured interviews, households were asked to name one preferred energy type per energy use. Equally, households were also asked to provide reasons for their mentioned energy preferences (figure 4.1).



	Firewood	Electricity	Dung
Cooking	91	7	2
Space Heating	91	7	2
Water Heating	98	2	0

Figure 4.1 Households energy and preferences (percentages of households).

It can be noted from figure 4.1, that firewood was the most preferred energy resource among the three main energy types. Firewood was mostly preferred for water heating (98%), cooking (91%) and space heating (91%). Electricity was the second preferred energy resource with 7% for cooking, 7% for space heating and 2% water heating. It also emerged that 2% of the communities of Senwabarwana Villages preferred dung for space heating and for cooking, respectively. None of the respondents preferred dung for water heating. These results confirm a previous research finding by the Department of Energy (DoE, 2013). That study reported that most South African communities, including electrified households still prefer and make use of solid fuels such as firewood and dung for cooking and heating. In the currect study the most common and frequently stated reasons, as the rationale for the use of these energy resources is that solid fuels are a cheaper form of energy than electricity.

4.3.3 Factors that influence household choices of energy resource

Through meta-analysis of 27 published reports and articles on firewood use from different parts of the world, the following were found to be the most common factors that influence households to use firewood (figure 4.2).

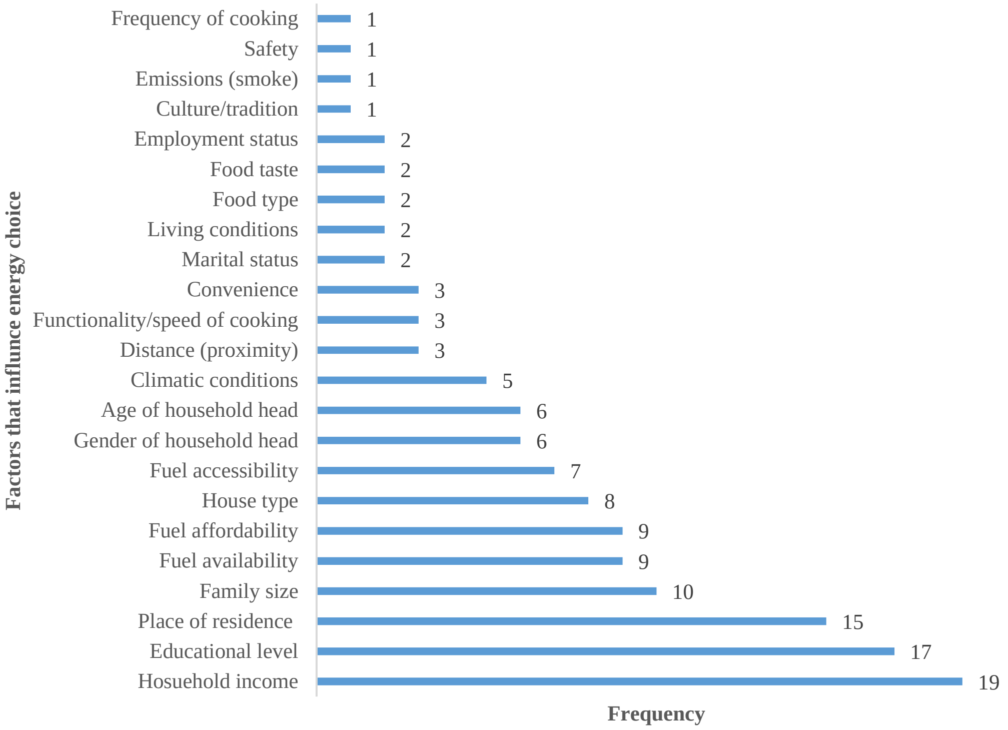


Figure 4.2 Factors that influence household choices of energy resource

The results show that 70.4% of households across different countries from which the reviewed data sources were published select energy type based on their household income, followed by 63% educational level, 55.5% place of residence, 37% family size, 33.3% fuel affordability, 33.3% fuel availability, 29.6% household type, 26% fuel accessibility, 22.2% gender of the head of household, 22.2% age of the head of household and other factors that make-up the remaining 20%. Comparatively, primary data results from the electrified Bapedi households of

Senwabarwana Villages identified six major factors that influence their choice of the type of energy they use (Figure 4.3).

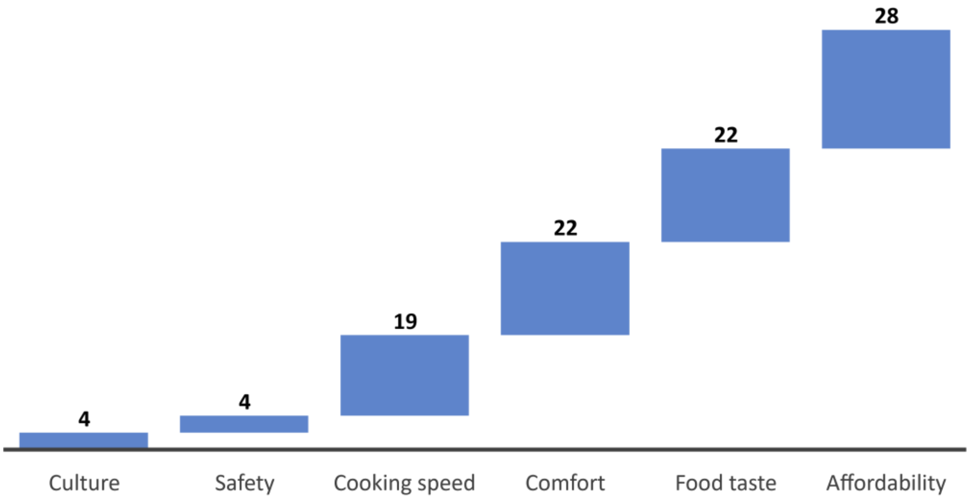


Figure 4.3 Factors that influence household preferences in energy type and uses in Bapedi households of Senwabarwana

Fuel affordability appeared as the main factor that influenced household preferences, use and choice of an energy resource, especially firewood. Perceptions about variability in food taste and comfortability associated with the use of an energy resource appeared to be the next least important, while safety and cultural considerations were the least important factors that households considered when deciding on the type of energy resource to be use.

a) Gender of the household head

The literature shows that men and women make different decisions about household energy (Puzzolo *et al*., 2014; Makonese *et al*., 2017). In most households, women are responsible for cooking and it is believed that the selection of fuel choice is their responsibility. Rahut *et al*. (2016) confirm that female household members play an active role in energy selection. However, WHO (2016) argues that men control the household budget in many societies and have more influence over energy selection. This implies that even if women wanted to switch to cleaner fuels, they may not be able to because of men's concerns about costs. According to Puzzolo *et al*. (2014), women who have their own income tend to use clean fuels. In this study, a total of 69 firewood using Bapedi households from Senwabarwana Villages participated in this study. The respondents were made of 9(13%) males and 60 (87%) females. The high female representative rate was found to be consistent with international literature, which shows that more women are often responsible for firewood use as they are traditionally the main members of households who make fire, cooking, keep homes warm and boil water for the family (Kohlin *et al*., 2012). Although, according to Kohlin *et al*. (2012: 4), "both women and men are involved in fuelwood collection but to varying degrees, with women often doing most of the collection labour".

This puts women at risk of being attacked by wild animals, being raped and hurt when cutting trees (Food and Agriculture Organisation of the United Nations, 2016). In some households, men are in control of cash accounts and therefore makes most household decisions including which fuel type must be used (Kohlin *et al*., 2012).

b) Household Income

According to StatsSA (2017, 56), household income refers to "all receipts by all members of a household in cash and in kind, in exchange of employment, or in return for capital investment, or receipts obtained from other sources such as social grants, pensions etc". Alternatively, Barr (2004, 12) defines household income "as the sum of consumption and change in net worth". In this study, StatsSA (2017) definition of household income is adopted. Household income is the leading factors that influences the choice and use of certain forms of energy resource in households. Available literature reveals that urban households generally have higher income than rural households (StatsSA, 2017; Chen *et al*., 2016). Consequently, high income is associated with urban households' preference for cleaner and more convenient fuels such as electricity (StatsSA, 2017; Chen *et al*., 2016).

Buba *et al*. (2017) reaffirmed that income capacity of a household influences its choice of types of energy. This trend was also observed in Kenya where low-income households rely completely on firewood and kerosene for their energy needs, while high-income households use electricity for lighting and biogas for cooking (Nyankone & Waithera, 2016). This precedence confirms the existence of an "energy ladder", a model that suggests households move from the use of solid fuels, which are considered dirty, to non-solid or clean fuels such as electricity, as their socio-economic status improves (Leach, 1992; Masera *et al*., 2000; Chen *et al*., 2016). The energy ladder model is commonly used to explain the household fuel choice transition in developing countries (Leach, 1992). This model identifies household income as a dominant factor that influences a household's choice of energy. The model divides household income levels according to three different rungs of the ladder. Each rung corresponds to the dominant fuel used by an income group and different income groups use different fuels and occupy different rungs (Mensah & Adu, 2015).

According to the energy ladder, high-income households use electricity, LPG and methanol. Middle-income households use kerosene and charcoal, whereas low-income households (also referred to as the poor) rely on firewood and cow dung (Leach 1992; Farsi *et al*., 2007; Mensah & Adu, 2015). A study by Rahut *et al*., (2014) supports the energy ladder theory, as it found that richer households used cleaner energy sources. The researchers confirm that an increase in income is directly proportional to an increase in accessibility to energy markets in Bhutanese households and ultimately triggers a switch from dirty to cleaner sources of energy.

c) Level of education

As discussed earlier in this chapter, meta-analysis results show that the level of education is the second major factor that influences the choice of the type of energy by households. According to Van Der Kroon *et al*. (2013), highly educated people prefer clean fuels to their less educated counterparts. In a multinomial logit, analysis of household cooking fuel choice in rural Kenya, Pundo and Fraser (2006) found that a woman's level of education influences the type of energy used for the household cooking. A study from China, confirmed that cooking with clean energy in households increases as family members attain higher educational levels (Chen *et al*., 2016). A Nigerian study, in which 87% of the respondents had low levels of both income and education, found that 70% of these respondents relied on firewood (Ebe, 2014). A Saudi-Arabian study found households with university-educated respondents ranked the highest in the use of electricity for cooking and heating (Al-Subaiee, 2015). In a similar study, those without formal education ranked the highest on the use of firewood for both cooking and heating (Al-Subaiee, 2016).

The moral of the discussion is that education is capable of or associated with the improvement of household income, thereby increasing household affordability. StatsSA (2017) reveals that 79.2% of South African adults who are without formal qualifications lived in poverty in 2015. According StatsSA (2017), formal post-secondary qualification is the required basic standard for the South African labour market. StatsSA (2016) classified educational levels into no schooling, preschool (Grade 0-R), primary (Grade R- 7), secondary (Grade 8-12) and post-secondary (higher certificate-doctorate) levels. In a South African context, it is understood that the progress through higher grades within a household is proportional to the shift from solid to non-solid fuels. Ado and Babayo (2016) who reiterated that educated households are inclined to use clean fuel confirmed this notion. According to Permana *et al*. (2015), the level of education dictates decision-making. By implication in a household, a member of a family (man or woman) with higher level of education often has more decision-making power. Consequently, such decision-making power also influences the choice of energy use for that household. However, the empirical results from structured interview of this study show a mixed finding about the influence of the level of education on the choice of energy type (figure 4.4).

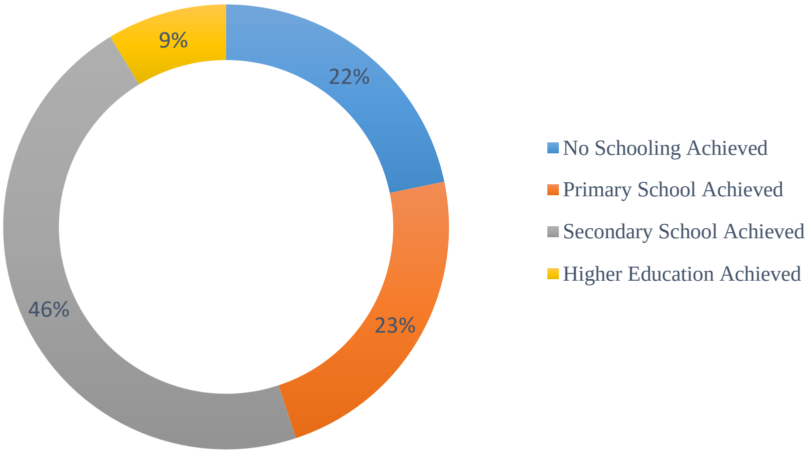


Figure 4.4 Highest level of eductaion achieved by respondent

The results reveal that 22% of the respondents did not have formal education, 23% only completed primary school (grade 1-7), 46% completed secondary school (grade 8-12), while only 9% had higher education (college or university qualification). These findings corroborate with the high unemployment rates in the study area and the high levels of household dependence in firewood as a major energy source. According to Van Der Kroon *et al*. (2013), highly educated people used clean fuels such as electricity while the least educated rely on dirty fuels (table 4.2).

Table 4.2 Influence of the level of education on energy use preferences

Level of educational	*Total number of respondents*	*Energy use preferences*							
		For cooking and water heating				*For space heating*			
		Firewood	*Electricity*	*Dung*	*LPG*	*Firewood*	*Electricity*	*Dung*	*LPG*
No schooling achieved	15	15				15			

Primary schooling achieved	16	15	1			16			
Secondary schooling achieved	32	27	3	1	1	31	1		
Higher education achieved	6	5	1			16			

This study could not establish association between level of education and energy use preferences among the electrified Bapedi households in Senwabarwana Villages.

d) Employment status of the respondents

Most respondents (97%) were the heads (often the mothers) of the households surveyed. Consequently, their responses about the total income households and employment status was proxy to and was a direct representative of their households’ employment profiles. Figure 4.5 presents the general employment profiles of the sampled households.

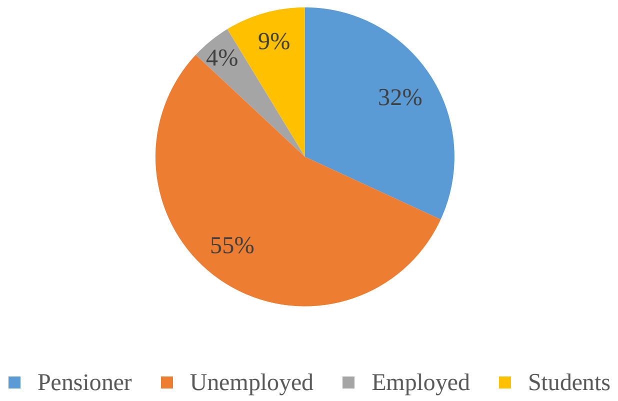


Figure 4.5 Employment status of respondents

It can be noticed from the results that employment status of households was ultimately grouped into four primary categories, during final analysis of the survey results. According to these results, 55% of households’ leaders are unemployed, 32% were pensioners, 9% students and only 4% were employed (including self-employed). These results present a serious socio-economic challenge of unemployment in the study area. The results confirm the report by National Treasury (2018), which reported a 27, 7% unemployment rate in South Africa and that South Africa’s current unemployment rate is the highest rate since 2003. Similarly, the employment profiles of this community also confirm the influence of household economic profile of the household choices of fuel. Surely, with high number of respondents (breadwinners) being pensioners, considering the monthly amount received by pensioner (discussed later), it is evident that these households have no luxury of choice of different energy alternatives other than firewood harvesting.

e) Place of residence

The Organisation for Economic Co-operation and Development (OECD, 2006) defines a place of residence as "the civil subdivision of a country (district, county, municipality, province, department, state, etc.) in which the individual resides". For purposes of this study, in line with the National Treasury (2011), a place of residence will be classified firstly into urban (category A, B1, B2 and B3 municipalities) and rural (category B4). According to StatsSA (2017), urban households generally reside in communities where basic services are accessible, as opposed to rural communities. Generally, urban households are regarded as being non-poor, while rural households are regarded poor. A study by Ding *et al*. (2016) finds that households' energy consumption in urban areas is higher per capita than the rural areas. The study also examines the difference in energy consumption between the Southern (Africa) and Northern (Europe) regions. Another impact of the area of residence is documented by Ogwumike *et al*. (2014) who reveal the use firewood is prohibited in some residential areas such as households residing in high-rise building or flats in urban areas.

f) Family size

Family size, as defined by Kamuzora (2001) is the number of people staying in a household, who share the expenses of that household. The United Nations, Department of Economic and Social Affairs, Population Division (UNDESA, 2017) defines family size as a "group of persons who make common provision of food, shelter and other essentials for living, as a fundamental socio-economic unit in human societies". In this study, both definitions of family size are accepted as having same meaning. Average family size ranges between 3-to-6 people per household (UNDESA, 2017). According to UNDESA (2017), Europe and North America often have smaller family sizes as opposed to large family sizes in Africa and the Middle East.

StatsSA (2017) demonstrates an association between poor households and larger family size. Larger family sizes are also associated with higher energy consumption than their smaller counterparts (Suliman, 2013; Rahut *et al*. 2016). The study by Rahut *et al*. (2016) concludes that households with bigger family sizes are more likely to use kerosene and dirty fuels like firewood. This finding confirms a previous Nigerian study by Ebe (2014) which states larger families use greater quantities of firewood and kerosene. Available literature highlights several impacts associated with family size. For example, Virola and Martinez (2007) point out that a larger family size results in greater spending on items such as household energy, food, shelter, clothing, health, education and other needs. Literature associate low educational levels to household income. A comparative statistical calculated monthly income against family sizes in the study area is further discussed (table 4.3).

Table 4.3 Household monthly income of respondents and family size

Parameters	*Family size*	*Monthly income (ZAR)*
Average	5.3	2227
Minimum	1	350
Maximum	19	18000
Mode	4	1645
Median	5	1645

Adapted from: Schwabe (2004) and Meyer & Nishimwe-Niyimbanira (2016)

In comparing the family sizes with household income based on the parameters discussed earlier, it is clear that families are higher than the minimum household income required per person. In the light of these results and the poverty threshold adopted from Schwabe (2004) and Meyer and Nishimwe-Niyimbanira (2016), the households of Senwabarwana village live under absolute poverty; they live below the poverty line, in general. For example, while a person who lives alone in a household is expected to survive by a minimum of R1115.00 per month, the study results shows that in general, one person in Senwabarwana village lives by a minimum of R350.00 per month. Most households were made up of four members who live by R1645.00 per month. The largest family size consists of 19 family members living out of R18000.00 per month, against the minimum of R11305.00. The latter is an exceptional case where the household income is enough for the family size. Author of this study finds household income to be the leading factor that influences the choice and use of certain forms of energy resource among households as also found by Buba *et al*. (2016) and Chen (2016).

Schwabe (2004) reveals that as family size increases household income reduces. For the purposes of this study, the framework developed by Schwabe (2004) and Meyer and Nishimwe-Niyimbanira (2016) has been adapted and used to investigate the relationship between family size and household income. Table 4 presents figures for 2001, 2013 and a recalculated threshold for 2018. These calculations and the threshold are in South African currency called a Rand (R).

The calculations follow a formula adopted from Meyer and Nishimwe-Niyimbanira (2016) who adjusted the 2001 family size vs household income from Schwabe (2004) by multiplying the minimum monthly income by the updated global poverty line, which was $2.00 at the time of calculations, to derive the 2013 threshold. In this paper, the 2018 minimum monthly threshold is determined using the World Bank's (2015) updated global poverty line of \$1.90. The following formula is used:

$$Y = X \times \$1.90 \qquad (1)$$

Where Y is the 2018 threshold, X is the 2001 threshold used by Schwabe (2004) and \$1.90 is the international poverty line set by the World Bank (2015) based on purchasing power parity. According to the World Bank (2015), the global poverty line is the acceptable minimum amount a person can live on per day in any country considering exchange rates.

g) Fuel affordability and cost

Affordability may be defined in terms of cash, or time required for self-collection of firewood, or for collection through hired labour. Affordability plays a decisive role in the use of firewood for cooking (Karima *et al*., 2016). Firewood is collected free; hence, it remains the cheapest energy source for cooking and heating, thus the most affordable. In support of this, Ifegbesan *et al*. (2016) confirm that firewood is the main fuel used for cooking by almost two-thirds of participants in Nigerian households. According to these studies, fuel cost variation can encourage or discourage households from using a fuel and/or promote a shift towards other fuel substitutes. However, it is important to understand that the price of fuel and cooking stoves can become an affordability issue in determining households' fuel choices (Malla & Timilsina, 2014). It should be noted that many low-income rural households, for example in Guatemala or India, purchase wood. Fuel affordability depends on fuel cost.

According to O'Sullivan and Sheffrin (2003), cost is the amount of money spent to acquire a thing. Rural households allocate a smaller portion of their expenditure to electricity, while urban households spend more on electricity (StatsSA, 2017). According to Suliman (2013), rural households rely more on biomass and kerosene due to affordability while urban households spend more electricity. Based on this fuel cost and affordability go hand in hand, therefore for this study the two are interlinked.

h) Fuel accessibility or availability

The availability of traditional fuels is measured by distance, for example distance to fuelwood collection point (Food and Agriculture Organisation (FAO), 2017). According to Buba *et al*. (2017), dependence on firewood in Nigeria is influenced by the availability of forest. Firewood is a major fuel in rural areas because it is often the only available, accessible and affordable fuel in the region (Suliman, 2013; IEA, 2014). Accessibility to fuel plays an important role in a household's fuel decisions. Communities without electricity are forced to use alternatives, which are mostly dirty fuels (DoE, 2013). In some cases, there is no access to alternatives and households use whatever is available (Hanna & Oliva, 2015).

i) Culture

The selection of fuel for cooking is also cultural. Sperber (1996) defines culture as ideas, customs and social behaviour of people or society. According to Baldwin *et al*. (2006) culture encompasses religion, food, what to wear, language, marriage, music, beliefs, what is right or wrong, how to sit at the table, how to greet visitors, how to behave with loved ones, and many other things. Based on these definitions, food taste, and food type are viewed as culture. It is therefore part of culture when Venda and Shangaan elders in northeast Limpopo, South Africa, prefer porridge cooked using firewood rather than electricity due to the difference in taste (Makhado *et al*. 2009). This is also the case in rural Mexican households, as well as in Kano, Nigeria; the respondents confirm that firewood gives flavour to the food (Maconachie *et al*. 2009; Ifegbesan *et al*. 2016). Bhojvaid *et al*. (2014) report the same experience in Uttar Pradesh and Uttarakhand, rural areas of India, where older men complain about food cooked on improved cooking stoves. Food taste is also identified as a major determinant in energy choice in Chiwundura communal area, Zimbabwe (Remigios 2014).

j) Age of the household head

Empirical findings show age is a factor in the selection of household fuel. Some studies find age is positively associated with a preference for traditional fuels (Buba *et al*., 2017; Rahut *et al*., 2016). Older heads of household are most resistant to new fuel technologies and cling to traditional fuels as a matter of habit compared to younger heads of household. Mekonnen and Kohlin (2009) find that households with older heads in major Ethiopian cities are much more likely to use wood and kerosene than electricity and charcoal while demand of wood increases with age. In addition, the results of this study also identified the potential influence of age on firewood use. Table 4.4 descriptively presents some age parameters based on central and variable measures of tendencies.

Table 4.4 Age profile of household representatives using firewood

Age parameter	*Value*
Mean (average)	49
Mode	67
Median	51
Standard deviation	18
Minimum	18
Maximum	84

Statistical analysis of the age variable shows that respondents of this study were all adult members of the households aged 18 to 84. The average age of respondents was 49, with many respondents aged 67 and half of the respondents above 51 years of age, at a standard deviation of 18 years. Clearly, the age profile combined with the gender profile of respondents give a good impression that most respondents were the heads (female or male) of those sampled households. This observation strengthens the confidence on the accuracy of their responses about firewood use and related information. In addition, the age profile also gives confidence to their lived experiences and knowledge of different plant species used for firewood. The literature reviewed indicates that older heads of households are more resistant to new fuel technologies and cling to traditional fuels as a matter of habit as compared to younger household head (Buba *et al*., 2017; Rahut *et al*., 2016).

4.4 Conclusion

This chapter analysed the factors that influence firewood use among the electrified households of Bapedi tribe from Senwabarwana Villages. The results confirm that firewood is one of the major energy resources used in households among Bapedi households in the study area, as is globally, based on available literature. Firewood serves as an alternative energy resource after electricity, and is the most preferred energy resource for cooking, as well as water and space heating in many developing countries. For cooking and water heating firewood ranks the highest among the available energy resources. The major drivers of firewood use in households are household income, educational status of a breadwinner, family size, and place of residence, fuel affordability and accessibility. This chapter also revealed that firewood use is among others, a psychosocial, economic and behavioural issue. Previous studies also consistently showed that the use of firewood in households also involve some levels of indigenous and socio-cultural perceptive elements. Several communities from the selected countries used firewood for cultural, belief and religious purposes. It is for these reasons, among others, that most communities do not stop using firewood even when they have access to electricity.

However, the results show that there is a gradual shift from dependence on firewood to alternative energy sources as household income and educational levels improve. Mostly, households shift from firewood as a primary energy source to electricity, only if the use of energy resource is more convenient or their economic status has improved significantly. The latter is primarily driven by convenience as a major factor of energy selection. In conclusion, the current study concludes that firewood use is primarily driven by convenience. The more convenient the source of energy, the more attractive it becomes to different households. In this context, socio-economic convenience, such as affordability and clean energy sources are taken into cognisance.

References

Abdul-Hakim, I. K. & Ibrahim, Y. (2017). Socio-economic Factors Influencing Household Energy Choices in Kano Metropolis, Nigeria. *American Journal of Energy Science*, 4(3), 10-17.

Abdullahi Buba, A., Abdu, M, Adamu, I., Jibir, A. & Usman, Y. I. (2017). Socio-economic determinants of household fuel consumption in Nigeria. *International Journal of Research Granthaalayah*, 5(10).

Ado, A. & Babayo, M.A. (2016). Determinants of fuels stacking behaviour among households in Bauchi Metropolis. *The Business and Management Review*, 7(3).

Advani, A., Johnson, P., Leicester, A. & Stoye, G. (2013). Household Energy Use in Britain: A Distributional Analysis. The Institute for Fiscal Studies: London.

Al-Subaiee, F.S. (2016). Socio-economic factors affecting the conservation of natural woodlands in Central Riyadh Area – Saudi Arabia. *Saudi Journal of Biological Sciences*, 23: 319-326

Bailis, R., Drigo, R., Ghilardi, A. & Masera, O. (2015). The global footprint of traditional woodfuels. *Nature Climate Change*, 5, 266-72

Baker, L.J. (2008). Urban Poverty: A Global View. The World Bank: Washington DC

Baldwin, J. R., Faulkner, S. L., Hecht, M. L. & Lindsey, S.L. (2006). Redefining Culture. Mahwah, NJ: Laurence Erlbaum Associates.

Barr, N. (2004). Problems and definition of measurement. Economics of the Welfare estate. New York: Oxford University Press, 121-124

Bhojvaid, V., Jeuland, M., Kar, A., Lewis, J. J., Pattanayak, S.K., Ramanathan, N., Ramanathan, V. & Rehman, I.H. (2014). How do People in Rural India Perceive Improved Stoves and Clean Fuel? Evidence from Uttar Pradesh and Uttarakhand. *Int. J. Environ. Res. Public Health*, 11, 1341-1358

Buba, A., Abdu, M., Adamu, I., Jibir, A. & Usman, Y.I. (2017). Socio-economic determinants of household fuel consumption in Nigeria. International *Journal of Research-Granthaalayah*, 5(10).

Chen Q, Yang H., Liu, T. & Zhang, L. (2016). Household biomass energy choice and its policy implications on improving rural livelihoods in Sichuan, China. *Energy Policy*, 93, 291 – 302.

City of Polokwane, Sustainable Energy Africa & University of Limpopo. (2016). Household energy use and supply survey of Dikgale Subdistrict of Polokwane, Limpopo. *Sustainable Energy Africa,* Cape Town

Department of Energy. (2013). A survey of energy related behaviour and perceptions in South Africa: The residential sector. Pretoria: South Africa

Department of Environmental Affairs. (2016). Draft strategy to address air pollution in dense-low income settlements. Government gazette, Pretoria: South Africa

Díez, H.E. & Pérez, J.F. (2017). Physicochemical Characterization of Representative Firewood Species Used for Cooking in Some Colombian Regions. *International Journal of Chemical Engineering*. Hindawi.

Ding, Y., Qu, W., Niu S., Liang, M., Qiang, W. & Hong, Z. (2016). Factors Influencing the Spatial Difference in Household Energy Consumption in China. *Sustainability*. MDPI

Duflo, E., Greenstone, M. & Hanna, R. (2008). Indoor air pollution, health and economic well-being. *SAPIENS*, 1, 1-9.

Ebe, F.E. (2014). Socio-Economic Factors Influencing the Use of Fuelwood in Urban Areas of Enugu State, Nigeria. IOSR *Journal of Business and Management*, 16(11), 147-151.

Ezzati, M. & Kammen, D.M. (2001). Indoor Air Pollution from Biomass Combustion and Acute Respiratory Infections in Kenya: An Exposure-Response Study. The Lancet

Farsi, M., Massimo, F. & Shonali, P. (2007). Fuel Choice in Urban Indian Households. *Environment and Development Economics*, 12, 757

Food and Agriculture Organisation (FAO). (2017). Incentivizing sustainable wood energy in sub-Saharan Africa: a way forward for policy-makers. Rome: Italy.

Glass, G.V. (1976). Primary, secondary and meta-analysis of research. Educational Researcher. University of Colorado, Boulder: Colorado.

Hanna, R. & Oliva, P. (2015). Moving up the Energy Ladder: The Effect of an Increase in Economic Well-Being on the Fuel Consumption Choices of the Poor in India". *American Economic Review*: Papers & Proceedings, 5, 242–246

Ifegbesan, A.P., Rampedi, I.T. & Annegarn, H.J. (2016). Nigerian households' cooking energy use, determinants of choice and some implications for human health and Environmental Sustainability. *Habitat international*, 55, 17-24

Inter-American Development Bank (IADB). (2017). Understanding the Drivers of Household. Energy Spending: Micro Evidence for Latin America. Latin America

International Energy Agency (IEA). (2010). World Energy Outlook. Paris, France. Accessed from http://www.worldenergyoutlook.org/media/weo2010.pdf on 28 January 2018

International Energy Agency (IEA). (2014). International Energy Agency Home Page. Accessed from http://www.iea.org/topics/energypoverty on 12 Decemeber 2017.

Kamuzora, C.L. (2001). Poverty and family size patters: comparison across countries. Research Report no 01.3 Dar Es Salaam: REPOA. Mkuki Nyota Publishers

Keller, G. (2014). Statistics for Management and Economics.10th Ed. Canada: Cengage Learning

Leach, G. (1992). The energy transitions. *Energy Policy*, 20(2), 116-123

Lee, L. Y. (2013). Household energy mix in Uganda. *Energy Economics*, 39, 252–261

Lin, W., Chen, B., Luo, S. & Liang. L. (2014). Factor Analysis of Residential Energy Consumption at the Provincial Level in China. *Sustainability,* 6, 7710-7724

Maconachie, R. Adamu, T. & Mustapha, Z. (2009). Descending the Energy Ladder, Oil Price Shocks and Domestic Fuel Choices in Kano, Nigeria. *Land Use Policy*, 26(4), 1090-1099.

Makhado, R.A., Potgieter, M.J. & Wessels, D.C.J. (2009). Colophospermum mopane Wood Utilisation in the Northeast of the Limpopo Province, South Africa. *Ethnobotanical Leaflets*, 13, 921-45.

Makonese, T., Ifegbesan, A.P. & Rampedi, I.T. (2017). Household cooking fuel use patterns and determinants across Southern Africa: Evidence from the demographic and health survey data. *Energy & Environment*, 29(1), 29-48.

Makonese, T., Masekameni, D.M., Annegarn, H.J. & Forbes, P.B.C. (2015). Influence of fire-ignition methods and stove ventilation rates on gaseous and particle emissions from residential coal braziers. *Journal of Energy in Southern Africa*; 26 (4).

Malla, S. & Timilsina, G. (2014). Household cooking fuel choice and adoption of improved cook stoves in developing countries: a review. Policy Research Working Paper 6903. World Bank.

Massawe, F.A., Bengesi, K.M.K. & Kweka, A.E. (2015). Patterns of Household Cooking Energy and Associated Factors: Experience from Kilimanjaro Region, Tanzania. *Intersect*, 8 (3).

Maurice, D. C., Umar, Y. & Zubairu, E. (2015). Analysis of Factors Influencing Fuelwood Consumption in Some Selected Local Government Areas of Taraba State, Nigeria. *Journal of Agricultural Economics, Environment and Social Sciences*,1(1), 163–168

Mekonnen, A. & Köhlin, G. (2009). Determinants of Household Fuel Choice in Major Cities in Ethiopia. Working Papers in Economics 399, University of Gothenburg, Department of Economics

Mensah, J. T. & Adu, G. (2015). An Empirical Analysis of Household Energy Choice in Ghana. *Renewable and Sustainable Energy Reviews*, 51, 1401–1411.

Meyer, D.F. & Nishimwe-Niyimbanira, R. (2016). The impact of household size on poverty: An analysis of various low-income township in the Northern Free State region, South Africa. *African Population Studies*, 30 (2).

Moeen, M.S., Sheikh, A.T, Muhammad, A.T., Saleem, M.S.S. & Rashid, S. (2016). Factors Influencing Choice of Energy Sources in Rural Pakistan. *The Pakistan Development Review*, 55 (4), 905–920

Mutua, J. & Kimuyu, P. (2015). Household Energy Conservation in Kenya: Estimating the Drivers and Possible Savings. Environment for Development: Kenya

National Treasury. (2011). Delivering municipal services in rural areas. Accessed form http://www.treasury.gov.za/publications/igfr/2011/lg/15.%20Rural%20services%202011%20LGBER%20-%20Final%20-%209%20Sept%202011.pdf on 03 May 2018.

National Treasury. (2018). "Budget review". Pretoria South Africa. Accessed from www.treasury.gov.za/documents/national%20budget/2018/review/FullBR.pdf on 16 June 2018

Nlom, J.H. & Karimov, A.A. (2015). "Modelling fuel choice among households in Northern Cameroon". Sustainability journal

Nyankone, B.O. & Waithera, N. (2016). Factors Influencing Choice of Sources for Domestic Energy Used in Households in Thuti Sub-Location, Othaya. *Journal of Energy Technologies and Policy*, 6(7)

Ogwumike, F.O., Ozughalu, U, M. & Abiona, G.A. (2014). Household Energy Use and Determinants: Evidence from Nigeria. *International Journal of Energy Economics and Policy*, 4(2), 248-262.

Organisation for Economic Co-operation and Development (OECD). (2006). Handbook of Vital statistics and Methods: United Nations Studies in Methods, Glossary. Accessed from https://stats.oecd.org/glossary/detail.asp?ID=2067 on 12 June 2018

O'Sullivan, A. & Sheffrin, S.M. (2003). Economics: Principles in Action. Upper Saddle River". New Jersey 07458: Pearson Prentice Hall.

Pundo, M. O. & Fraser, G.C.G. (2006). Multinomial logit analysis of household cooking fuel choice in rural Kenya: The case of Kisumu district. Agrekon: *Agricultural Economics Research, Policy and Practice in Southern Africa*, 45(1), 24-37.

Puzzolo, E., Rehfuess, E, Stanistreet, D., Pope, D. & Bruce, N. (2014). WHO guidelines for indoor air quality: household fuel combustion-Review 7: Factors influencing the adoption and sustained use of improved cook stoves and clean household energy. Geneva: World Health Organisation

Rahut, D.B., Behera, B. & Ali, A. (2016). Household energy choice and consumption intensity: Empirical evidence from Bhutan. *Renewable and Sustainable Energy Reviews*, 53, 993 – 1009.

Rahut, D.B., Das, S., De Groote, H. & Behera, B. (2014). Determinants of household energy use in Bhutan. *Energy*, 69, 661-672.

Remigios, M.V. (2014). The significance of culture as a household energy determinant. The case of Chiwundura Communal area, Zimbabwe. *Journal of Human Ecology*, 46(3), 343-349.

Riphahn, R.T. & Serfling, O. (2002). Item Non-response on Income and Wealth Questions. Discussion paper series. Germany

Schwabe, C. (2004). Fact Sheet: Poverty in South Africa. Pretoria: Human Sciences Research Council (HSRC). Accessed from https://www.sarpn.org/documents/d0000990/ on 12 June 2018.

Sepp, S. (2014). Multiple-Household Fuel Use a balanced choice between firewood, charcoal and LPG. GIZ, MBZ Berlin

Smith, K. (2000). National Burden of Disease in India from Indoor Air Pollution. Proceedings of the National Academy of Science. www.pnas.org

Sperber, D. (1996). Explaining Culture. Oxford: Blackwell

Statistics South Africa. (2015). Income dynamics and poverty status of households in South Africa. Census 2011. Pretoria: Statistics South Africa

Statistics South Africa. (2016). Community survey 2016: Provinces at a glance. Pretoria: Statistics South Africa

Statistics South Africa. (2017). Poverty Trends in South Africa: An examination of absolute poverty between 2006 and 2015. Pretoria: Statistics South Africa

Suliman, K.M. (2013). Factors affecting the choice of households’ primary cooking fuel in Sudan. *The Economic Research Forum* (ERF). Egypt

Timko, J.A. & Kozak, R.A. (2016). The influence of an improved firewood cook stove, Chitetzo mbaula, on tree species preference in Malawi. *Energy for Sustainable Development*, 33, 35-60.

Uhunamure, S. E, Nethengwe, N.S. & Musyoki, A. (2017). Driving forces for fuelwood use in households in the Thulamela municipality, South Africa. *Journal of Energy in Southern Africa* 28 (1).

United Nations, Department of Economic and Social Affairs, Population Division (UNDESA) (2017). Household Size and Composition around the World 2017 – Data Booklet (ST/ESA/ SER.A/405)”.

Van der Kroon, B., Brouwer, R. & Van Beukering, J.H. (2013). The Energy Ladder: Theoretical Myth or Empirical Truth? Results from a Meta- Analysis. *Renewable and Sustainable Energy Reviews*, 20, 504-513.

Virola, R.A. & Martinez, A.M. (2007). Population and poverty nexus: Does family size matter? Paper presented at the 10th National Convention on statistics (NCS), EDSA Shangri-La Hotel. 1-2 October.

World Bank. (2012). Gender equality and development. Social development papers. World development report. Paper No 125. August 2011.

World Bank. (2015). World Bank Forecasts Global Poverty to fall below 10% for first Time: Major Hurdles Remain in Goal to End Poverty by 2030. Accessed from http://www.worldbank.org on 12 June 2018.

World Health Organisation (WHO). (2016). Burning opportunity: Clean household Energy for Health, Sustainable Development, and Wellbeing of Women and Children. WHO Press, Geneva, Switzerland.

CHAPTER 5: ETHNOBOTANICAL PHENOMENOLOGY OF FIREWOOD PLANTS USED BY BAPEDI HOUSEHOLDS[3;4]

5.1 Introduction

Different communities use a variety of plant species for innumerable social, economic and environmental benefits. Ethnological studies associate plant species and their different uses to ethical and socio-cultural dynamics of communities within areas where such plant species are found. This phenomenon has also been significantly investigated in indigenous environmental knowledge studies. In the current study area, available literature shows that ethnobotanical studies have been devoted to traditional medicines (Semenya, 2012, Mongalo & Makhafola, 2018). To a limited extent, there is also sketchy literature on ethnobotanical plants for fruits and other uses. However, none has been found this far on the phenomenology of firewood plant species used specifically by Bapedi households of Sewabarwana Village, located at the Limpopo Province, in South Africa.

The knowledge of firewood ethnobotanical phenomenology of the Bapedi households is important for a number of reasons, namely (1) to improve on existing knowledge of multiple ethnobotanical uses of indigenous plant species within Senwabarwana Village, (2) to document competing and complementary plant uses, and (3) to document the relations between multiple uses of a plant and status in South Africa. For example, some plant species serve as firewood when they are burnt and the smoke thereof has medicinal benefits to the household members indirectly inhaling the smoke. However, available literature has reported highly about ill-health consequences of household firewood emitted smoke, with little if any about the healing potentials of the smoke. The other significant value that the ethnobotanical phenomenology of firewood plants in the current study area contributes is to highlight potential tree species that need protection as pointed out in a previous study by Corlett (2016).

According to Semenya (2013) and Food and Agriculture Organisation (FAO, 2017), commonly used indigenous plant species are vulnerable to deforestation, overexploitation, urban

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[3] Semenya K and Machete F. Ethnobotanical phenomenology of firewood plants used by Bapedi Households. Accepted: The Indilinga African Journal for Indigenous Knowledge Systems.

[4] Semenya K and Machete F: *African indigenous criteria for domestic firewood selection used by Bapedi households of Senwabarwana Village, South Africa*. First international Conference on Sustainable Management of Natural Resources (ICSMNR) 15-17 October 2018. Bolivia Lodge, Polokwane. Http//www.univern.ac.za/icsmnr/. ISBN: 978-0-620-82267-1.

development, agricultural expansion and unsustainable firewood use. Further, despite easy access to or availability of plant species within communities, indigenous or, often rural communities have a defined set of tree species that are characterised and classified as suitable firewood, than their urban counterparts. In indigenous household different plant species are known by and have indigenous names. The indigenous naming of each tree often relates to the history, features and functional use of each tree. Thus, not every tree log is a firewood in these indigenous households. Certain plants species are sacred and as such, cannot be used as firewood. The use of various plant species for firewood differs further with households believe systems traditional family classes, totems and many other indigenous systems. This analogy is a complete contrast to households in urban settlements, where any tree trunk or a branch thereof is a firewood (FAO, 2017a). According Jin *et al*. (2017), a firewood is any wooden material that can be used as renewable energy source or fuel. Firewood is thus classified into softwood or hardwood (FAO (2017a; 2017b). The latter criteria classified wood according to its suitability of different functionalities and preferential potentials of users. For an example, with reference to firewood, as opposed to hardwood, softwood is associated with (1) lower energy content, (2) burning quicker, (3) producing less heat (FAO 2017a).

A study in Nigeria, by Adeyemi and Ibe (2014) confirmed that most of the firewood species were unattainable harvested from the natural forests. Food and Agriculture Organisation (2015; 2017) observed an annual decrease in global forest cover of 7.6 million hectares to 3.3 million hectares between 2010 and 2015. The latter study attributes such global land cover decrease to unsustainable firewood use. The association between global landcover decrease and unsustainable firewood harvesting has stimulated a serious debate among scientist. In the latter argument, Hosonuma, Herold, Sy and Brockhaus (2012) argue forest degradation is driven by numerous factors, which differ, from one country to another. In the latter argument, Hosonum et al. (2012) point out that in Asia and Latin America the main driver of deforestation is timber demand, while in Africa firewood is the main driver. In Saudi Arabia, the high demand for firewood has reportedly caused high pressure on the existing vegetation cover and has consequently reduced density and frequency of some plant species such as *Acacia tortilis* (Al-Abdulkader, Shanavaskhan, Al-Khalifah & Nasrounm, 2009). *Acacia tortilis* is one of the most preferred firewood tree species commonly use in most parts of Saudi Arabia (Al-Abdulkader et al. 2009).

The second challenge associated with firewood use is indoor and ambient air pollutions associated with the smoke emitted during combustion. This challenge is exacerbated when the firewood combustion process is undertaken improperly ventilated and open areas. According to WHO, (2016) firewood smoke is a trigger to multiple respiratory health problems and can exacerbate existing health problems such as TB, HIV/Aids and asthma, to mention a few. These firewood challenges are in addition to well-known one, i.e, global warming and climate change, greenhouse gas emissions. The most commonly known climate related gases associated with firewood use include carbon dioxide (CO_2) emissions from unsustainable wood harvesting and methane (CH_4) and black carbon (the most light-absorbing component of particulate matter) emitted during incomplete combustion (FAO, 2017). In appreciating both the importance of firewood use and its associated risks within communities, this paper analysed firewood species used in Senwabarwana Village, South Africa to understand the reasons behind local people's preferences of various firewood species.

5.2 Materials and methods

A survey study design was followed during data collection as defined in Machete and Shale (2015). Structured interviews were used to identify common firewood plant species used by households in Sinwabarwana Villagers. Participating households were purposefully selected, based on their use of firewood (Leedy & Ormrod, 2010). Descriptive statistics were used to analyse the collected data, and priority plant species were identified, based on their frequency of use by households (e.g;Winter et al., 1966; Venter & Venter, 1996; Boon, 2010; Thomas & Grant, 1998; Van Wyk, Van Wyk, & Van Wyk, 2000; Palgrave, 2002; Plantzafrica, 2018; Joffe, 2001; Lourens, 2004; Grant & Thomas, 2000; Schmidt, Lotter, & McCleland, 2002; Van Wyk & Gericke, 2000). In-depth reviews and meta-analysis of the identified plant species was used to align the descriptive features of each identified plants with their common, botanical and scientific names. This analysis also helped this study to identify other different ethnobotanical uses of these plants, the number of uses each plant has and the potential relations such uses have in the legislative or plant status in South Africa.

In conducting this multi-analysis of primary data, authoritative sources such as national legislation were given the priority in naming the trees, previous South African studies received second priority, frequency of publications identifying a plant species by a particular name and years of publication of such studies were ranked the least, respectively.

5.3 Results and discussion

5.3.1 Common firewood plant species used in Senwabarwana Village

Table 5.1 indicates that the most common identified and harvested firewood plant species belong to seventeen different botanical families. These plants were mainly trees. Most (28%) of the species identified belong to the Fabaceae family, 13% belong to Combretaceae, 9.3% belong to Combretaceae, 6.3% belong to Anacardiaceae and another 6.3% belong to Sapotaceae, while the remaining 37,2% are shared by 12 other groups with each group having 3.1% of plant species. The dominating plant species belong to the Fabaceae family. Similarly, the studies conducted by Semenya and Maroyi (2012); Rankoana (2016); and Constant and Tshisikhawe (2018) in different parts of the Limpopo Province and by Tabuti *et al*. (2003) in Uganda found that most plant species used for medicinal and firewood belong to the same Fabaceae family. This might be attributed to the fact that the *Fabaceae* family is one of the most diverse plant families in the world (Gomes *et al*., 2018). The diversity of this family is observed in its reproduction mode. The plants in this family grow in all sorts of soil and climate. The results also revealed that all the plant species in table 5.1 are indigenous to the Senwabarwana community. Indigenous plants are plant species that occur naturally in an area without human intervention. For this reason, these plants have other uses apart from firewood use.

Table 5.1 Firewood species used by bapedi households in Senwabarwana

Local name (tree number)	**Botanical name**	**Common name**	**Family**	**Description**	**National conservation status**	**Protection status**
Motswiri	*Combretum imberbe*	Leadwood	Combretaceae	A deciduous tree up to 50 ft. high with pale grey bark splitting into small rectangles. The young branches are whitish and frequently spine-like. It has yellow or greenish flowers. The wood is chocolate coloured with a thin layer of whitish sapwood. The wood is exceedingly hard, heavy, strong, and durable (De Winter et al., 1966; Venter & Venter, 1996).	Least concern	Protected
Mohweleri	*Combretum apiculatum subsp. apiculatum*.	Red bush willow	Combretaceae	A semi-deciduous to deciduous tree, up to 9 m tall. Young branches are covered with reddish-brown fibrous bark – but grey to light brown, smooth, and scaly in old specimens. Has light green leaves, sticky and glossy, greenish-yellow to yellow and heavily scented. The wood is heavy and hard with the sapwood, which is yellowish, and the heartwood, which is dark reddish-brown to dark brown (Venter & Venter, 1996, p 178; Boon, 2010).	Least concern	Not protected
Moduba	*Olinia emarginata*	Mountain hard pear	Oliniaceae	Small to medium-sized evergreen tree with attractive tiny pale to dark pink flowers and red berries, glossy dark green opposite leaves. The tips of the leaves are rounded, notched and are usually tinged with pink or red (De Winter et al., 1966; Venter &Venter, 1996).	Least concern	Not protected
Mohlatswa	*Englerophytum magalismontanum (Sond.) T.D.Penn.*	Wild plum	Sapotaceae	Small to medium-size evergreen tree, up to 15 m tall depending on the habitat it grows in. It has a greyish, smooth and slightly scaly bark. The young leaves are golden brown; found at the tips of the branches. The flowers are small, star-shaped and brownish-pink in colour (Thomas & Grant, 1998; Van Wyk, Van Wyk & Van Wyk, 2000; Coates-Palgrave, 2002).	Least concern	Not protected
Mogobagoba	*Podocarpus falcatus*	Yellowwood	Podocarpaceae	An evergreen tree, up to 46 m. It has spirally arranged leaves with parallel veins and smooth margins. Light yellow wood with no distinction between sapwood and heartwood (Venter & Venter, 1996).	Least concern	Protected

Mosehla	*Peltophoram africanum*	African wattle	Fabaceae	A semi-deciduous to deciduous tree, up to 15 m tall, with a dense, rounded to spreading crown. It has smooth and grey bark on the young branches and twigs covered with reddish-brown hairs but brown to grey and rough, with lengthwise grooves on the older branches and stems. The leaves are twice compound with 4–9 pairs of pinnae, each bearing 10–23 pairs of grey-green leaflets; the growth tip, leaf stalk and rachis covered in dense reddish-brown hairs. It has bright yellow flowers. The wood has light brown sapwood and a soft, dark brown to blackish heartwood that is heavy (De Winter et al., 1966; Venter & Venter, 1996).	Least concern	Not protected
Mmupudu	*Mimusops zeyheri*	Red milkwood	Sapotaceae	A medium to large evergreen tree, up to 20 m tall, with an upright stem. The bark is pale to dark grey, rough, and cracks into squares. The leaves are spirally arranged along the stems, alternate, dark green. The flower stalks are slender, 30 mm long with reddish hairs; flowers whitish yellow, 10 mm in diameter, with a sweet aroma. It has a hard wood (De Winter et al., 1966; Venter & Venter, 1996; Boon, 2010).	Least concern	Not protected
Moretshe	*Dichrostachys cinera subsp.africana*	Sickle bush	Fabaceae	A semi-deciduous tree, up to 7 m tall, with an open crown. On young branches, the bark is green and hairy but dark grey-brown and longitudinal fissured on older branches and stems, but smooth on spines formed from modified side shoots. Two leaflets with 20–27 pairs of leaflets each. The wood has yellowish sapwood, and a deep red-brown, very dense, hard, closely grained and heavy heartwood. The inner bark is very tough and used for making rope (Venter & Venter, 1996).	Least concern	Not protected
Monakanakane	*Terminalia sericea*	Silver cluster-leaf	Combretaceae	A small to medium-sized tree, up to 6 m tall. Dark grey to brownish bark. Pale green leaves covered with silvery silky hair with small, cream to pale yellow flowers. The wood is yellow and hard, which makes it suitable for furniture (Coates-Palgrave, 2002).	Least concern	Not protected
Mushu	*Acacia tortilis*	Umbrella thorn	Fabaceae	A semi-deciduous flat-topped tree, up to 20 m tall. Grey to dark brown bark. Thorns in pairs. Feathery, short, hairy leaves. Spherical cream heads flowers. Wood with a light brown sapwood showing conspicuous annual rings. The heartwood is red and very heavy (Venter &Venter, 1996; De Winter et al., 1966).	Least concern	Not protected
Mohlakauma	*Fueggea virosa*	White berry bush	Phyllanthaceae	A dioecious bushy shrub, up to 3 m tall, with small, thorn-like branches. It has a reddish-brown to brown bark; green leaves with very small, creamy green flowers. It produces fruits that are eaten by people and animals (Coates-Palgrave, 2002; Boon, 2010).	Least concern	Not protected
Moselesele	*Dichrostachys cinerea*	Hairy sickle bush	Fabaceae	A small acacia-like tree, up to 5-6 m tall. It has a dark grey-brown bark, with bi-pinnate leaves. Each pinna has 27 pairs of leaflets. It has fluffy lilac flowers; hard, durable wood, which is resistant to termites (Thomas & Grant, 1998; Coates-Palgrave, 2002; De Winter et al., 1966).	Not evaluated	Not protected

Mmilo	*Vangueria infausta*	Wild medlar	Rubiaceae	A small tree, up to 8 m tall, with smooth grey bark peeling in irregular small strips. The leaves are single, oppositely arranged and light green. Greenish-white to yellowish flowers. This tree is believed to possess evil powers and the wood may not be used, not even as a fuel (Boon, 2010; Coates-Palgrave, 2002).	Least concern	Not protected
Mphata	*Lonchocarpus capassa*	Apple leaf	Fabaceae	A semi-deciduous tree, up to 12 m tall, with an open rounded crown. On the young branches, the bark is smooth, grey but flaking on older branches and stems. It has unevenly compound leaves with 1–3 pairs of opposite leaflets and a larger terminal one, texture hard, glossy above and grey-green beneath, with prominent midribs, the stalk thickset and velvety. The flowers are mauve to violet petals and the calyx covered with grey velvety hairs. The wood is hard and dense and has sapwood, which is off-white, and the heartwood is orange-brown (Venter & Venter, 1996).	Least concern	Protected
Sephatwa	*Gymnosporia buxifolia*	Pioneer spike thorn	Celastraceae	A small evergreen tree, up to 7 m tall, with light brown and smooth bark. Has white to cream-coloured flowers (Boon, 2010).	Least concern	Not protected
Morula	*Sclerocarya birrea subsp. Caffra*	Marula	Anacardiaceae	A deciduous tree, up to 18 m tall. The bark has prominent scars; it has unevenly compound leaves; and forms yellow fruit when matured. The wood has light reddish-brown to whitish with no definite heartwood. The fruits are edible (De Winter et al., 1966; Venter & Venter, 1996).	Least concern	Protected
Mokgalo	*Ziziphus mucronata subs. Mucronata*	Buffalo thorn	Rhamnaceae	A deciduous tree, up to 17 m tall, with an open round to spreading crown. On the young branches, the bark is smooth and reddish-brown but rough, dark grey to brown and longitudinally fissured on the older branches and stems. The spines paired, one hooked, 5-7 mm long and the other straight, 10-20 mm long; some forms with hardly any spines. The leaves are alternate, simple, smooth and shiny, up to 70 x 50 mm toothed margin in the upper two-thirds, leaf base asymmetrically round. The flowers are clusters in the leaf axils, coloured yellowish green. The wood is heavy with a pale yellow-brown sapwood, the heartwood light brown, tinged red, heavy, and hard and often with a twisted grain. It produces edible fruits which can be dried and ground to a meal and cooked to produce a kind of porridge. The seeds can be used as a coffee substitute. The young leaves can be eaten as spinach (De Winter et al., 1996; Venter & Venter, 1996; Boon, 2010).	Least concern	Not protected

Mokgalo	*Acacia nigrescens*	Knob thorn	Fabaceae	Large tree, up to 30 m tall, with a rounded or spreading crown. It has a yellowish and peeling bark on young twigs but dark brown with black prickles on prominent knobs on older branches. The young branches have paired black hook thorns. It has grey green leaves. The wood is hard and strong with a yellow sapwood and a dark brown, hard, strong and tough, heavy heartwood. Produces dark brown, thinly textured, splitting pod borne in pendant clusters (Venter & Venter, 1996; De Winter et al., 1966; Plantzafrica, 2018).	Least concern	Not protected
Mokwerekwere	*Nuxia congesta*	Brittlewood Nuxia	Buddlejaceae	A quick-growing, evergreen tree or shrub, 2-20 m tall. It has a pale grey-brown to dark brown shedding bark and hairy branches. The leaves are hairy, dark green, slightly leathery and variable in shape and size. The flowers are small, about 5 mm long, tubular and creamy white, often tinged with mauve or purple, especially in bud. It has a hard and durable, whitish-yellow wood, which is used for fence posts and for fuel (Coates-Palgrave, 2002; Plantzafrica, 2018).	Least concern	Not protected
Mohlware	*Olea europaea subsp.africana*	Wild olive	Oleaceae	A neatly shaped evergreen tree with a dense spreading crown (9 x 12 m) of glossy grey-green to dark-green foliage. The leaves are grey-green to dark-green above and greyish below. The rough, grey bark sometimes peels off in strips. It has sprays of tiny, lightly scented white to greenish flowers; spherical, thinly fleshy fruits (either sweet or sour) which ripen purple-black. A tea can be made from the leaves. It has hard, heavy and beautiful golden-brown wood (De Winter et al., 1966; Venter & Venter, 1996; Joffe, 2001).	Least concern	Not protected
Moretlwa	*Grewia flava*	Velvet raisin	Malvaceae	The velvet raisin plant (*Grewia flava*), also known as wild raisin or brandy bush, is a low-growing shrubby plant with distinctive greyish-green hairy leaves. It has star-shaped yellow flowers which make way for the berry-like fruit (Lourens, 2004).	Least concern	Not protected
Mokata	*Combretum hereroense*	Russet bushwillow	Combretaceae	A semi-deciduous tree, up to 10 m tall; bark on young branches peeling in strips but dark grey, rough and longitudinally fissured on older branches and stems. It has cream-coloured to yellow leaves; wood without a prominent sapwood but brown on the outside to reddish-brown on the inside, hard and heavy (Venter & Venter, 1996).	Least concern	Not protected
Mothetlwa	*Grewia flava*	Brandybush	Tiliaceae	A small tree up to 4 m tall with an open crown; smooth, dark grey bark on older trees. It has grey to greyish-green and fine, hairy leaves with yellow followers. The wood has light coloured sapwood and a brown, fine-grained hard heartwood (Venter & Venter, 1996).	Least concern	Not protected

Mogwana	*Grewia monticola Sond*	Grey or Silver raisin	Malvaceae	A frost-resistant, small tree that is adaptable to all soils, from clay to sand, and does not require much water. It has bright yellow flowers. The stem is crooked. Its bark is rough, grey-brown. The young branches are densely hairy, white to pale brown, becoming grey to brown and rough. The leaves are alternate, simple, obliquely elliptic-oblong to ovate, 25–90 x 10–50 mm, apex pointed. They are 3-veined from the asymmetrically lobed or rounded base, ± leathery, slightly rough above due to scattered star-shaped hairs or smooth, green to grey-green and somewhat wrinkled, below velvety grey or white, with scattered russet hairs on veins, margin irregularly and coarsely serrate. The petiole (leaf stalk) is about 5 mm long and hairy. It has a red wood (Coates-Palgrave, 2002; Boon, 2010).	Least concern	Not protected
Mooka	*Acacia xanthophloea*	Fever tree	Fabaceae	A deciduous tree, up to 18 m tall, with knobs on the trunks and branches. It has yellowish-white flowers; a hard wood, which is drought and termite resistant (Boon, 2010; Plantzafrica, 2018).	Least concern	Not protected
Modumela	*Kirkia wilmsii* (Venter & Venter, 1996) *Kirkia acuminata oliv* (De Winter et al., 1966)	White Seringa (De Winter et al., 1966). Mountain Syringa (Venter & Venter, 1996)	Simarubaceae	A tall tree of 18 m high with greenish-white flowers and greyish-white wood (De Winter et al., 1966; Venter & Venter, 1996).	Least concern	Not protected
Mochidi	*Ximenia caffra*	Sour plum	Olacaceae	A deciduous tree, up to 6 m tall, with an untidy open crown. The bark is dark grey and rough. It produces thinly fleshy, oval, attractive fruits (drupes) which are 25 mm long, glossy, deep red with white spots (Venter & Venter, 1996; Plantzafrica, 2018).	Least concern	Not protected
Monoko	*Ozoroa paniculosa (Sond.) R.Fern. & A.Fern*	Resin tree	Anacardiaceae	This is an evergreen to semi-deciduous tree, up to 7 m tall. The bark is grey, and it cracks and turns rough with age (Grant & Thomas, 2000; Schmidt, Lötter & McCleland, 2002).	Least concern	Not protected
Mothobethobe	*Acacia exuvialis*	Flaky thorn	Fabaceae	It is a small thorn tree, with a height of 2–5 m, often multi-stemmed and has fine, feathery foliage forming a broom-like crown. The bark is smooth and peels in large, orange-brown flakes, leaving a smooth, yellow-brown under-surface. The thorns are very long and white, and it has a few yellow, ball-like flowers for most of the summer. The branches are often shiny glutinous in parts, having an oily appearance as a result (Plantzafrica, 2018; Boon, 2010).	Least concern	Not protected
Mokgwa	*Acacia burkei* Benth	Black monkey thorn	Leguminosae	The tree has grey-yellow to black, rough bark – occasionally with knob thorns and a wide spreading crown. Dark-coloured to black hooked thorns. The wood is very dark brown and heavy (De Winter et al., 1966; Venter & Venter 1996; Plantzafrica, 2018).	Least concern	Not protected

Motshe	*Cussonia paniculata* Eckl. & Zeyh.	Highveld cabbage tree	Araliaceae	This is a large evergreen shrub tree, rarely exceeding 5 m in height. The wood is soft and light in weight. The leaves provide good fodder for stock. The thick root can be peeled and eaten raw as food or as a source of water (Van Wyk & Gericke, 2000; Plantzafrica, 2018).	Least concern	Not protected
Moselaphala	*Acacia permixta*	Hairy acacia	Fabaceae	A multi-stemmed shrub or small tree, up to 4 m tall. It has slender, weakly ascending branches with pale to dark chestnut or reddish-brown bark. The branches have spreading grey to whitish hairs. The leaves are clothed with spreading hairs. This plant grows in woodland, thorn scrub and grasslands on dry, sandy hillsides and flats; on soil that is usually derived from granite (Lock, 1989; Kyalangalilwa & Boatwright, 2013).	Least concern	Not protected
Mowana	*Grewia spp*	Raisin bush	Malvaceae	A deciduous shrub with hermaphrodite flowers. This plant grows in light sandy, medium loamy and heavy clay soils (Plantzafrica, 2018; Toptropicals, 2018).	Least concern	Not protected

Most of the species identified in table 5.1 belong to the botanical family of fabaceae species. In a 2003 study, Tabuti *et al.* (2003) also found that most plant species used for firewood in Uganda to belong to the same Fabaceae family. The results also reveal that all the plant species in table 1, are indigenous to Senwabarwana Village. Indigenous plants are plant species that occur naturally in an area without human intervention. Braitstein and Njenga, (2014), argues that wood from indigenous trees has two main distinctive qualities that qualifies it as a suitable firewood, namely; (1) it burns more efficiently and (2) it produces more heat, as opposed to firewood from exotic plant species. From this list of firewood plant species, this study has identified 10 most frequently use firewood plant species by Bapedi households of Senwabarwana Village (figure 5.1).

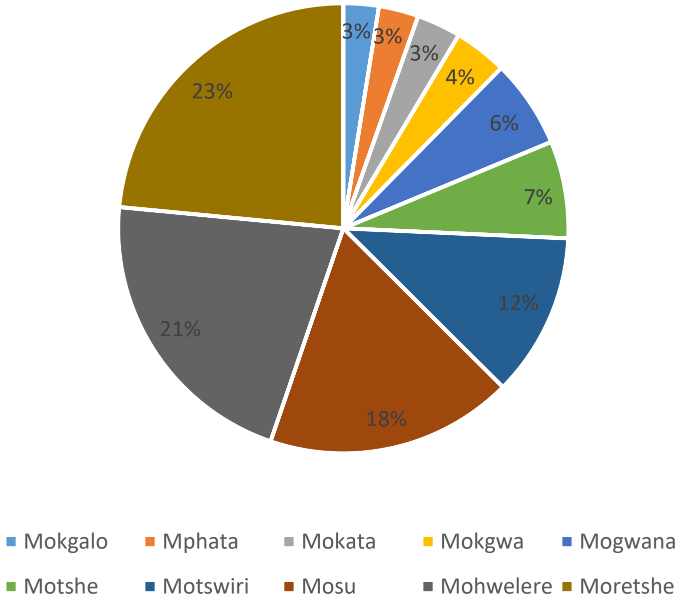


Figure 5.1 Priority firewood plant species used in Senwabarwana Village

According to the results in figure 5.1, moretshe is the most frequently use and preferred by most by 23% of households in Senwabarwana Village, followed by mohweleri (21%), mosu (18) and motswiri (12%). The remaining plant species among the ten, namely motshe, mogwana and mokgwa were used by 7%, 6% and 4% of the sampled households, respectively, while only 3% of the sampled households used each of the mokata, Mphata and mogalo. Further analysis of these firewood plant species was based on their national conservation and protections status, as detailed in table 5.1 above. This analysis revealed that according to the South African national conservation status, all the identified firewood plant species are of least concern. However, their legislative protection status varies among plant species. Mphata and motswiri are the only two of the ten species that are legislative protected species in South Africa.

5.3.2 Factors used to determine suitability of plant species for firewood

Empirical data from the Bapedi households from Senwabarwana Village revealed 13 reasons (factors) that are used as a criterion to determine the suitability of plant materials or logs as firewood (figure 5.2).

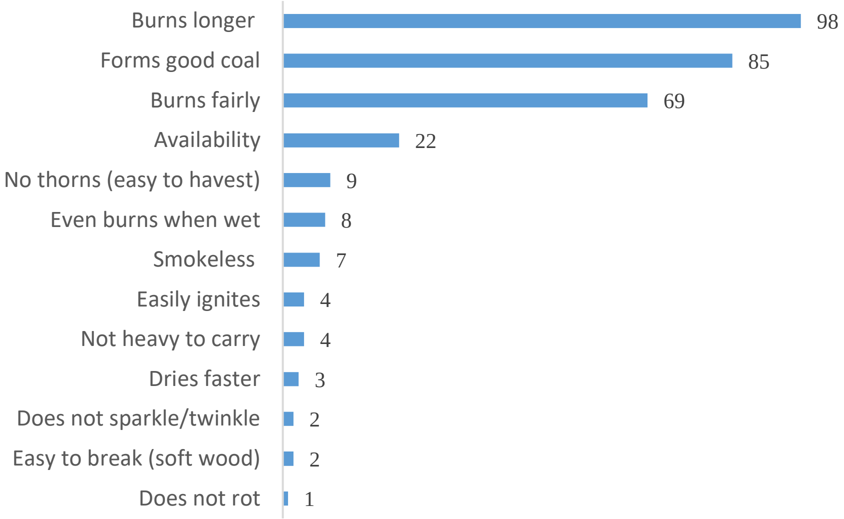
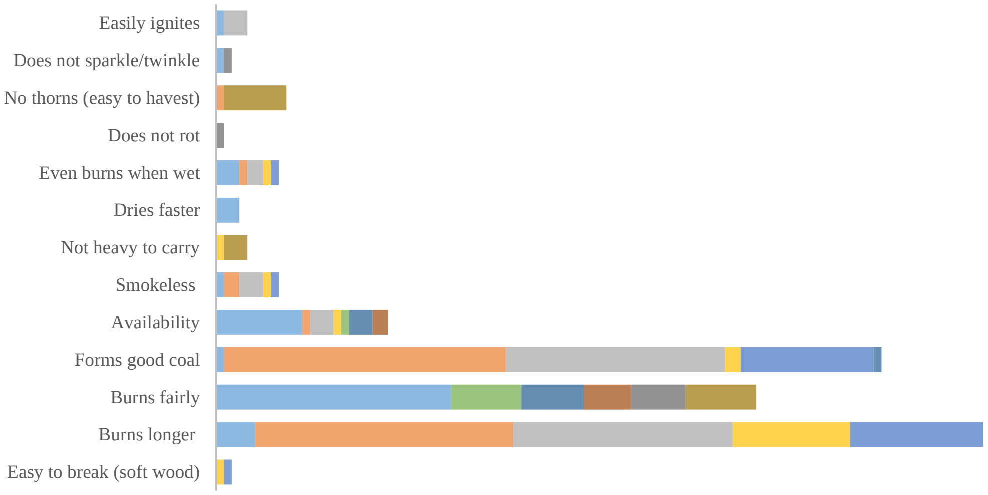


Figure 5.2 Factors used to determine suitability of plant species for firewood (rating in %)

The results show that 98% of households selected firewood species based on the plant's known qualities of burning longer than other plant species. The second and third priority factors used by the Senwabarwana Villagers were the plant's qualities of forming good coal and burning fairly by 85% and 69% of households, respectively. The third bottom factors were that the wood burns faster (3%), does not sparkle (2%), it easily breaks (2%) and that it does not rot (1%). These results add to existing literature about the qualities of firewood. According to Sigaud and Luhanga (2001), naturally all trees can be used as firewood or energy fuel. However, combustion of plant materials or logs differ from one species to another due to different plant species properties. The results of the current study are thus confirming the previous findings by Cardoso *et al*. (2012), about the properties of plants that make its materials suitable for firewood. Such findings also concur with Tietema *et al.* (1991), Tabuti *et al.* (2003), Munalula and Meincken (2009), who founds that the ideal firewood species possess qualities such as high heat or energy content, high wood density, low ash content and low moisture content. Put differently, the latter studies' findings are like one or more of the 13 reasons provided by the Bapedi households of Senwabarwana Village. Tabuti *et al*. (2003) and Cardoso *et al*. (2012) add that while all tree species could be used for firewood, there are species that are generally preferred by different communities. In addition, the former studies also pointed out that firewood is selected based on scientific variables such as (1) moisture content, (2) calorific value, (3) density and (4) ash content. This study brings in a non-scientific or academic variable that indigenous communities use as factors or criteria to select suitable firewood among different plant species readily available within communities. Figure 5.3 presents the link between the ten-plant species and the reasons that makes these species a preference for the Bapedi of Senwabarwana households.



	Easy to break (soft wood)	Burns longer	Burns fairly	Forms good coal	Availability	Smokeless	Not heavy to carry	Dries faster	Even burns when wet	Does not rot	No thorns (easy to havest)	Does not sparkle/twinkle	Easily ignites
Mosu		5	30	1	11	1		3	3			1	1
Mohweleri		33		36	1	2			1		1		
Moretse		28		28	3	3			2				3
Motshe	1	15		2	1	1	1		1				
Motswiri	1	17		17		1			1				
Mokata			9		1								
Mokgwa			8	1	3								
Mokgalo			6		2								
Mphata			7							1		1	
Mogwana			9				3				8		

Figure 5.3 The link between the ten-plant species and the reasons for preference by the Bapedi of Senwabarwana households.

According to the results in figure 5.3, each of the ten commonly used firewood plant species are preferred for one or more of the 13 qualities. The results are self-explanatory, in that the number of households that prefer each firewood plant species and the different attributes associated with the choice are both graphically and numerically presented above.

5.3.3 Multi-complimentary and competing uses of ethnobotanical species

Part of the phenomenology of the identified ethnobotanical species found in the Bapedi households of Senwabarwana reveals multiple, complementary and competing uses of these plants. Table 5.2 shows that plant species are not only used for firewood, but also for traditional medicinal purposes, beverages, consumed as food and used for household utensils.

Table 5.2 Number of different benefits or uses of each indigenous tree

Name of the plant		**KNOWN USES**										**TOTAL**	**Times mentioned by the community N=69**
		Medicinal			**Beverages**	**Fodder**	**Fence post/mine props**	**Food**	**Household utensils**	**Furniture**	**Fuel**		
	Part used	*Roots*	*Bark*	*Leaves*	*Fruit*	*Leaves*	*Wood*	*Fruit*	*Wood*	*Wood*	*Wood*		
Motswiri		1		1			1		1	1	1	6	14
Mohwelere				1			1				1	3	38
Moduba		1	1	1			1		1		1	6	2
Mohlatswa		1	1		1			1			1	5	3
Mogobagoba			1					1		1	1	4	1
Mosehla		1	1	1			1				1	5	2
Mmupudu		1		1	1	1		1			1	6	2
Moretshe				1		1	1				1	4	32
Monakanakane		1	1								1	3	4
Mosu			1			1	1		1		1	5	48
Mohlakauma		1	1		1		1	1			1	6	4
Moselesele		1				1	1		1	1	1	6	3
Mmilo		1		1	1			1			1	5	4
Mphata		1	1	1		1				1	1	6	10
Sephatwa		1	1							1	1	4	2
Morula			1	1	1		1	1		1	1	7	3
Mokgalo		1	1	1	1	1	1	1	1		1	9	10
Mokwerekwere		1	1				1	1	1		1	6	3
Mohlware				1						1	1	3	1
Moretlwa		1			1	1		1			1	5	2
Mokata		1					1	1			1	4	13
Mothetlwa		1			1			1			1	4	1
Mogwana					1			1			1	3	4
Mooka		1							1		1	3	17
Modumela		1	1								1	3	3
Mochidi				1	1			1			1	4	1
Monoko			1								1	2	1

Mothobethobe		1						1			1	3	1
Mokgwa		1	1				1			1	1	5	10
Motshe		1	1	1		1					1	5	18
Mowana		1									1	2	1
Moselaphala						1	1	1	1		1	5	3
Total		**22**	**16**	**13**	**10**	**9**	**14**	**15**	**8**	**8**	**32**		

The results in table 5.1 also show that 32 identified firewood plant species were found to have one or multiple known uses in indigenous African communities. These uses include medicinal use, beverage making, fodder, fuel, fence post/mine household utensils/ornaments and furniture. Through descriptive statistical analysis, this study found that on average, the common firewood plant species of the Bapedi households in Senwabarwana Village have six uses, while half of the 32 plants in table 5.2 have less or more than four uses. In addition, the results show that most of these plant species have six uses; the lowest has a single use, while the highest has nine uses. The standard deviation of the 32 plant species' uses was 1.5. This shows that there is multi, complementary and competing uses of each plant species which might lead to a rapid deterioration of the indigenous plants in Senwabarwana if not used sustainable or managed properly. For example, a plant (*Mokgalo*) with nine uses is beneficial to the community since all its parts are used to cater for community needs and might be in threat of extinction. However, this plant is of least concern as indicated in table 5.1. Every part of the plant is useful in its own way. Figure 5.4 indicates the proportions of different plants used.

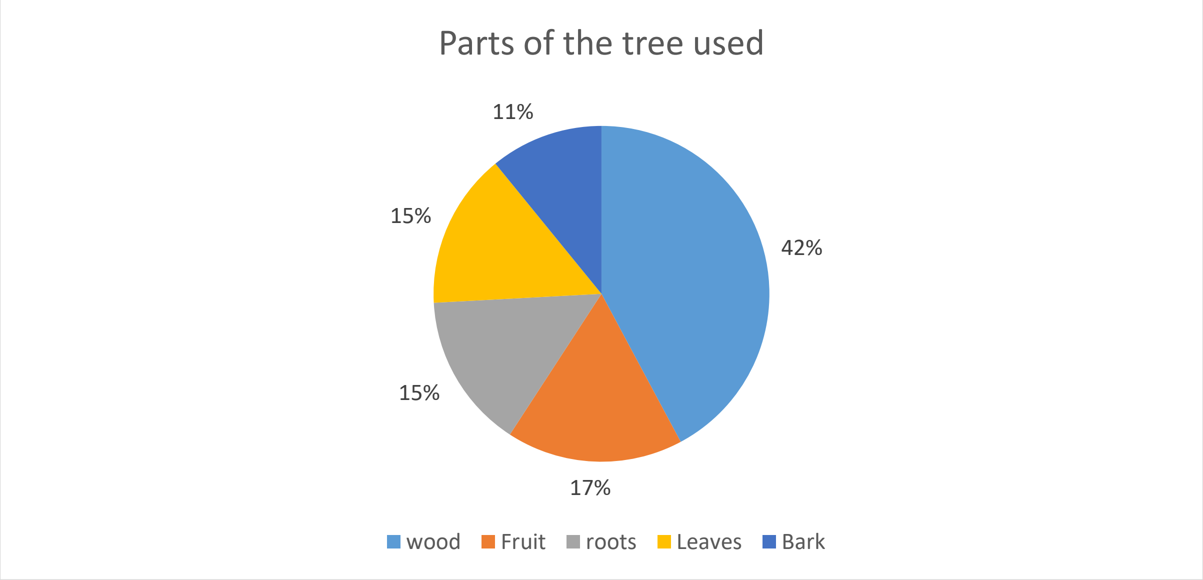


Figure 5.4 Proportion of different parts of ethnobotanical plant species used

Wood represents the highest proportion (42%) of the parts used, is used for furniture, household utensils, fence posts and as fuel. Altogether 17% of the parts used is represented by the fruit used for beverages and as food. Roots and leaves are used 15% each, mainly for medicinal purposes and fodder respectively, while the lowest proportion (11%) is represented by the bark.

5.3.4 Firewood harvesting methods used

Households often use the nearest forests for the harvesting and collection of wet (39%), dry (24%) and 37% of both wet and dry wood. An axe is used to cut down trees. Even firewood protected legally are harvested – the community indicated that they also cut the protected plants. Illegal harvesting will lead to the extinction of valuable indigenous plant species. Some households purchased firewood from local firewood traders who used donkey carts, tractors, cars and wheelbarrows, at a South African currency rate of ZAR70.00 to ZAR350.00. Approximately 4% of the households always bought firewood, 63% collected it from the nearest forest and 33% alternated between buying and self-collection from the forest. The most common transportation methods among those who do self-harvesting and collection included head logs and wheelbarrows (figure 5.5).

(a) Head logs use

(b) Wheelbarrow use

Figure 5.5 Common firewood transportation methods used by households

Firewood was collected mostly by women 60 (87%) in comparison to men 9 (13%). The results confirm available literature that highlights that women are mostly responsible for firewood harvesting and transportation (Kohlin *et al*., 2012). Previous studies attribute this practice to several safety, rape and other risks for women. However, it must be noted that this is not the focus of the paper. Firewood collection frequencies range from daily to one per annum among households (figure 5.6).

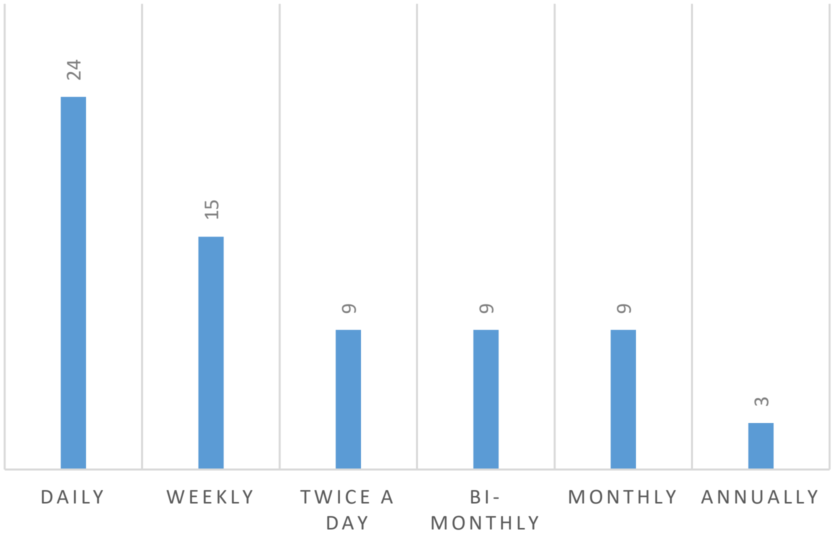


Figure 5.6 Firewood collection frequency per household (n=69)

According to the responses of household representatives, 35% of the household harvest firewood daily, 22% weekly, 13% harvest twice a day, monthly and bi-monthly concurrently, with only 4% of the households harvesting once per annum. The frequency of firewood harvesting is important in this study, primarily for sustainability aspects of firewood plants in the study areas. This observation is also a factor of plant species' availability, and the travelling distances of households to find firewood, in the light of the possible extinction of certain plant species. This is also a subject for discussion in a different publication, which is currently in press.

5.3.5 Conservation methods

It was found that the community in Senwabarwana do not have conservation methods of plants. They travel long distances to collect firewood when the nearby forests show signs of deforestation. Some families without trucks and donkey carts opted to buy wood. The local communities should be educated on the sustainable methods of harvesting and managing the indigenous plants.

5.4 Conclusion

This study analysed the ethnobotanical phenomenology of firewood plants used by Bapedi households in Senwabarwana, South Africa. Data was collected from a total of 69 households. Through descriptive statistical methods, 32 firewood plant species were analysed. An in-depth review of the identified firewood plant species was conducted to determine the scientific names of these species and other ethnobotanical uses of these plants. All species are harvested in the communal area. Indigenous plants provide a plethora of ecosystem services to support human needs for food, medicines, and other livelihoods. The harvesting methods used in this community are not sustainable putting most of the indigenous plants at risk of extinction. It is therefore recommended that with the help of the local municipality, indigenous methods of harvesting be implemented. Since there are methods of conservation, agroforestry could be considered as a method of conservation.

References

Adeyemi, A.A., & Ibe, A.E. (2014). Patterns of firewood exploitation and utilisation in peri-urban and rural areas of Owerri zone in Southern Nigeria. *Nigerian Journal of Agriculture, Food and Environment*, 10(3), 113–119.

Ado, A., & Babayo, M.A. (2016). Determinants of fuels stacking behaviour among households in Bauchi Metropolis. *The Business and Management Review*, 7(3), 84–97.

Al-Abdulkader A.M., Shanavaskhan A.E., Al-Khalifah N.S. & Nasrounm, T.H. (2009). The economic feasibility of firewood plantation enterprises in Saudi Arabia. *Arab Gulf J. Sci. Res*, 27, 1–6.

Atkins, P. & De Paula, J. (2006). *Physical Chemistry*; 8th edition. Freeman: New York.

Bahru, T., Asfaw, Z., & Demissew, S. (2012). Indigenous knowledge on fuel wood (charcoal and/or firewood) plant species used by the local people in and around the semi-arid Awash National Park Ethiopia. *Journal of Ecology and the Natural Environment*, 4(5), 141-149.

Blouberg Municipality. (2018). Draft integrated development plan 2018/2019-2021. Accessed from http://www.blouberg.gov.za on 10 August 2018.

Boon, R. (2010). *Pooley's trees of Eastern South Africa*. Flora & Fauna Publications Trust, Durban.

Braitstein, P., & Njenga, M. (2014). Women, poverty and forest destruction: Despite sensitisation, womenfolk continue to cut indigenous trees for firewood. Accessed from https://www.researchgate.net/...Women_poverty_and_forest_destruction...womenfolk on 25 March 2018.

Buba, A., Abdu, M., Adamu, I., Jibir, A., & Usman, Y.I. (2017). Socio-economic determinants of households' fuel consumption in Nigeria. *International Journal of Research-Granthaalayah,* 5 (10), 348–360.

Cardoso, M.B., Ladio. A.H, & Lozada, M. (2012). The use of firewood in a Mapuche community in a semi-arid region of Patagonia, Argentina. *Biomass and Bioenergy,* 46, 155–164.

Carr, J.D. (1976). *The South African Acacias*. Conservation Press, Johannesburg.

Chen, Q., Yang, H., Liu, T., & Zhang, L. (2016). Household biomass energy choice and its policy implications on improving rural livelihoods in Sichuan, China. *Energy Policy* 93, 291–302.

Coates-Palgrave, C. (2002). *Keith Coates Palgrave Trees of southern Africa*, 3rd Ed. Struik, Cape Town.

Coates-Palgrave, K. (1988). *Trees of southern Africa,* 2nd Ed. Struik, Cape Town.

Constant, N.L. & Tshisikhawe, M.P. (2018). Hierarchies of knowledge: ethnobotanical knowledge, practices and beliefs of the VhaVenda in South Africa for biodiversity conservation. *Journal of Ethnobiology and Ethnomedicine* 14(56). DOI: 10.1186/s13002-018-0255-2.

Davidson-Hunt, I.J., Jack, P., Mandamin, E., & Wapioke, B. (2005). Iskatewizaagegan (Shoal lake) plant knowledge: An Anishinaabe (Ojibway) ethnobotany of northwestern Ontario. *Journal of Ethnobiology*, 25(2), 189-227.

De Winter, B., De Winter, M., & Killick, D.J.B. (1966). Sixty-six Transvaal trees. Botanical research institute in collaboration with the Department of Forestry. Transvaal Provincial Administration.

Department of Agriculture, Forestry and Fisheries. (2016). Government Gazette. List of Protected trees. Accessed from https://cer.org.za/wp-content/uploads/1999/04/List-of-protected-tree-species.pdf on 15 March 2018.

Department of Energy. (2013). A survey of energy related behaviour and perceptions in South Africa: The residential sector. Accessed from http://www.energy.gov.za/.../Survey%20of%20Energy%20related%20behaviour%20and%2 on 20 April 2018.

Díez, H.E., & Pérez, J.F. (2017). Physicochemical Characterization of Representative Firewood Species Used for Cooking in Some Colombian Regions. *International Journal of Chemical Engineering*. Volume: 2017. Hindawi. https://doi.org/10.1155/2017/4531686

Driscoll, D. Milkovits, G. & Freudenberger, D. (2000). Impact and Use of Firewood in Australia. CSIRO Sustainable Ecosystems. Canberra.

Esterhuyse, N. (2001). *Remarkable trees of southern Africa*. Briza Publications, Pretoria**.**

Food and Agriculture Organisation of the United Nations. (2016). Guidance Note: Meeting Fuel and energy needs in protracted crises. The SAFE approach. Rome: Italy. Accessed from http://www.fao.org/publications on 10 March 2018

Food and Agriculture Organisation. (2017a). Incentivizing sustainable wood energy in sub-Saharan Africa: a way forward for policy-makers. FAO, Rome: Italy.

Food and Agriculture Organisation of the United Nations (2017b). Sustainable woodfuel for food security. A smart choice: green, renewable and affordable. Rome. Accessed from http://www.fao.org/publications 15 May 2018.

Food and Agriculture Organisation. (2003). State of Forest and Tree Genetic Resources in Dry Zone Southern Africa Development Community Countries. FAO, Rome: Italy

Glassman, I., & Yetter, R.A. (2007). *Combustion*; 4th ed. Academic Press: Burlington, MA.

Gomes, G. D., Silva, G.S., Silva, D.L.S., De Oliveira, R.R. & Da Conceicao, G.M. (2018). Botanical Composition of Fabaceae Family in the Brazilian Northeast, Maranhão, Brazil. *Asian Journal of Environment & Ecology*, 6(4), 1-10.

Grant, R., & Thomas, V. (1999). Sappi tree spotting. Tree identification made easy, KwaZulu-Natal coast and Midlands. Jacana, Johannesburg.

Heuzé V., & Tran, G. (2017). Buffalo thorn (Ziziphus mucronata). Feedipedia, a programme by INRA, CIRAD, AFZ and FAO. Accessed from https://www.feedipedia.org/node/81 on 10 May 2018

Hosonuma, N. Herold, M. Sy. V.D., Fries, R.S.D., & Brockhaus, M. (2012). An assessment of deforestation and forest degradation drivers in developing countries. *Environ. Res. Lett.*

Jan, G., Khan, M.A., Khan, A., Jan, F., Khan, R., Ahmad, M., Rehman, A., Danish, M., Asif, M., Khan, S., Zafar, M. & Jan. M. (2011). An Ethnobotanical Survey on Fuel Wood and Timber plant Species of Kaghan Valley, Khyber pakhtoonkhwa Province, Pakistan. *African Journal of Biotechnology*, 10(82), 19075-19083

Jin, S.L., Schure, J., Ingram, V., & Yoo, B. (2017). Sustainable woodfuel for food security. A smart choice: green, renewable and affordable. *Food and Agriculture Organization of the United Nations*, Rome. Accessed from http://www.fac.org/publications on 10 May 2018.

Joffe, P. (2001). *Creative gardening with indigenous plants – a South African guide.* Briza Publications, Pretoria.

Knox, A.J. (2012). Fuelwood and informal income generation**.** Dissertation submitted in partial fulfilment of an MPhil, Energy Research Centre, University of Cape Town: Cape Town.

Kohlin, G. Sills, E.O., Pattanayak, S.K., & Wilfong, C. (2012). Energy, Gender and Development. What are the linkages? Where is the Evidence? Accessed from http://www.worldbank.org/socialdevepment 15 May 2018.

Lambe, F., Jürisoo, M., Lee, C., & Johnson, O. (2015). Can carbon finance transform household energy markets? A review of cookstove projects and programmes in Kenya. *Energy Research and Social Science*, 5(2015), 55–56.

Leedy, P.D., Ormrod, J.E. (2010). Practical research planning and design. New York: Pearson Education Limited.

Machete, F. & Shale, K. (2015). Classification of unregulated landfills by waste stream analysis method, a case of Chief Albert Luthuli Municipality, South Africa. *African Journal of Science, Technology, Innovation and Development*, 7(6), 446-452.

Makhado, R.A., Potgieter, M.J., & Wessels, D.C.J. (2009). Colophospermum mopane wood utilisation in the Northeast of the Limpopo Province, South Africa. *Ethnobotanical Leaflets* 13, 921–45.

Malik, K., Ahmad, M., Zafar, M., U, R., Mahmood, H.M., Parveen, B., Rashid, N., Sultana, S., Shah, S.N. & Lubna, L (2019). An ethnobotanical study of medicinal plants used to treat skin diseases in northern Pakistan. *BMC Complementary and alternative medicine*, 19(210). https://doi.org/10.1186/s12906-019-2605-6.

Maroyi, A. (2012). Local plant use and traditional conservation practices in Nhema communal area, Zimbabwe. *International Journal of African Renaissance Studies-Multi-inter and Transdisciplinarity*, 7(1), 109-128.

Martinez, G.J. (2015). Cultural patterns of firewood use as a tool for conservation: A study of multiple perceptions in a semiarid region of Cordoba, Central Argentina. J*ournal of Arid Environments*, 121, 84–99.

Mavhura, E. & Mushure, S. (2019). Forest and wildlife resource-conservation efforts based on indigenous knowledge: The case of Nharira community in Chikomba district, Zimbabwe. *Forest Policy and Economics*, 105, 83-90.

Munalula, F., & Meincken, M. (2009). An evaluation of South African fuelwood with regard to calorific value and environmental impact. *Biomass and bioenergy*, 33, 415–420.

National Research Council. (1980*)*. Firewood Crops: Shrub and Tree Species for Energy Production. Washington, DC: The National Academies Press. https://doi.org/10.17226/21317.

Plantzafrica. (2018). South African plants. Retrieved from http://www.pza.sanbi.org.

Ramos, M.A., & De Albuquerque, U.P. (2012). The domestic use of firewood in rural communities of the Caatinga: How seasonality interferes with patterns of firewood collection. *Biomass and Bioenergy*, 39, 147–158.

Rankoana, S.A. (2016). Sustainable Use and Management of Indigenous Plant Resources: A Case of Mantheding Community in Limpopo Province, South Africa. *Sustainability*, 8(221),

Schmidt, E., Lötter, M. & McCleland, W. (2002). Trees and shrubs of Mpumalanga and Kruger National Park. *Jacana Publishers*, Johannesburg.

Schroeder, H. & Gonzalez, N.C.P. (2019). Bridging knowledge divides: The case of indigenous ontologies of territoriality and REDD+. *Forest Policy and Economics*, 100, 198-206

Semenya, S.S. & Maroyi, A. (2012). Medicinal plants used by the Bapedi traditional healers to treat diarrhoea in the Limpopo Province. S. Afr. J. *Ethnopharmacol*, 144, 395–401.

Semenya, S., Potgieter, M. & Erasmus, L. (2012). Ethnobotanical survey of medicinal plants used by Bapedi healers to treat diabetes mellitus in the Limpopo Province, South Africa. *Ethnopharmacol*, 141, 440–445.

Semenya, S.S., Potgieter, M.J., & Erasmus, L.J.C. (2013). Indigenous plant species used by Bapedi healers to treat sexually transmitted infections: Their distribution, harvesting, conservation and threats. *South African Journal of Botany*, 87(2013), 66–67.

Shackleton, C.M., Guthrie, G., Keirungi, J. & Stewart, J. (2003). Fuelwood availability and use in the Richtersveld National Park, South Africa. Pretoria: *Koedoe*, 46(2), 1–8.

Shackleton, C.M., McGarry, D., Fourie, S., Gambiza, J., Shackleton, S.E. & Fabricius. C. (2007). Assessing the effects of invasive alien species on rural livelihoods: Case examples and a framework from South Africa. *Human Ecology*, 35, 113–127. DOI 10.1007/s10745-006-9095-0

Sigaud, P. & Luhanga, J. (2001). SADC Sub-Regional Workshop on Forest and Tree Genetic Resources. *Forest Genetic Resources*, 28, 41–44.

Smit, N. (1999). *Guide to the Acacias of South Africa.* Briza Publications, Pretoria.

Sood, S.K., Nath, R. & Kalia, D.C. (2001). Ethnobotany of Cold Desert Tribes of Lahoul-Spiti (N.W. Himalaya). Deep Publications, New Delhi.

Statistics South Africa. (2016). Community survey 2016: Provinces at a glance. Pretoria: Statistics South Africa. Accessed from http://www.statssa.gov.za/wp-content/uploads/2016/.../Annual_Report_2016_Book_1_.pdf on 15 May 2018

Tabuti, J.R.S., Dhilliona, S. S., & Lyea, K.A. (2003). Firewood use in Bulamogi County, Uganda: species selection, harvesting and consumption patterns. *Biomass and Bioenergy*, 25, 581–596.

Thomas, V. & Grant, R. (1998). *SAPPI tree spotting. Highveld and the Drakensberg.* 1998. Jacana, Johannesburg.

Tietema, T., Dithlogo, M., Tibone, C., & Mathalaza, N. (1991). Characteristics of eight firewood species of Botswana. *Biomass and Bioenergy*, 1(1), 41–46. http://dx.doi.10.1016/0961-9534(91)90050-M

Timko, J.A., & Kozak, R.A. (2016). The influence of an improved firewood cookstove, Chitetzo mbaula, on tree species preference in Malawi. *Energy for Sustainable Development*, 33, 53–60. http://dx.doi.org/10.1016/j.esd.2016.04.002.

Ullah, S. & Bibi, S. (2018). Ethnobotanical survey of medicinal plants of Musamina District Malakand and Khyber Pukhtoonkhwa, Pakistan. *Academia Journal of Medicinal Plants*, 6(6), 122-126.

Van Wyk, B., & Gericke, N. (2000). *People's Plants – A guide to useful plants of southern Africa*. Briza Publications.

Van Wyk, B., Van Wyk, P., & Van Wyk, B.E. (2000). *Photographic guide to the trees of southern Africa.* Briza Publications, Pretoria.

Vasicek, C.A., & Gaugris, J.Y. (2014). Household Firewood Utilization around the Hlatikhulu Forest Reserve, South Africa. *Ethnobotany Research & Applications*, 12, 597–605. Accessed from http://www.ethnobotanyjournal.org/vol12/i1547-3465-12-597.pdf on 23 February 2018.

Venter, F. & Venter, J. (1996). *Making the most of indigenous trees.* Briza Publications, Pretoria.

World Bank. (2012). Gender equality and development. Social development papers. World development report. Paper No 125. Accessed from https://www.openknowledge.worldbank.org/hanle/10986/4391 on 18 February 2018.

World Health Organisation (WHO). (2016). Burning opportunity: Clean household Energy for Health, Sustainable Development, and Wellbeing of Women and Children". WHO Press, Geneva, Switzerland.

World Health Organization. (2013). Public Health and Environment (PHE): Household air pollution – Population using solid fuels. Geneva.

Zhen, L., Liu, X.L., Wie, Y.J., Yang, L., Long, X., Du, B., Li, F., & Cao, X. (2011). Consumption of ecosystem services: A conceptual framework and case study in Jinghe watershed. *Resources and Ecology*, 2, 298–306.

CHAPTER 6: THE RISKS ASSOCIATED WITH VOLATILE ORGANIC COMPOUNDS FROM THE COMBUSTION OF HOUSEHOLD FIREWOOD

6.1 Introduction

The burning of firewood in poorly ventilated kitchens for cooking over open fires is a matter of great concern because it exposes occupants to indoor air pollutants. Firewood smoke contains a complex mixture of pollutants such as particulate matter, inorganic gases (e.g. carbon monoxide, nitrogen oxides, and sulphur dioxides), polycyclic aromatic hydrocarbons (PAHs) and volatile organic compounds (VOCs), which could have harmful effects on the environment and human health (Nielsen *et al*., 2008; Williams *et al*., 2012). Many studies have been conducted involving the monitoring of both individual gaseous pollutants (e.g. carbon monoxide, nitrogen oxides, and sulphur dioxides) and particulate air pollutants (Kapwata *et al*., 2018; Olave *et al*., 2017; Mitchell *et al*., 2016; Parajuli *et al*., 2016; Joon *et al*., 2014). However, the monitoring of volatile organic compounds (VOCs) in kitchens where firewood is used for cooking has received little attention in the scientific literature.

VOCs are chemicals that contain carbon, hydrogen and oxygen and are gases at room temperature (Nielsen *et al*., 2008). According to USEPA (2018), VOCs “are organic chemical compounds whose composition makes it possible for them to evaporate under normal indoor atmospheric conditions and pressure”. VOCs are carcinogenic compounds and are precursor pollutants contributing to the formation of both ground-level ozone and particulate matter (Danish EPA, 2016; Olave *et al*., 2017). The most important class of VOCs comprises benzene, toluene, ethylbenzene and xylene (BTEX), which receive attention due to their abundance in the ambient atmosphere, their deleterious impacts on public health, and their function in atmospheric chemistry (USEPA, 2018; Danish EPA, 2016; Parajuli *et al*., 2016). According to Morakinyo *et al*. (2017), BTEX are international environmental priority pollutants due to their potentially harmful effects on human health. Photochemical reactions of BTEX pollutants can generate secondary pollutants, such as ozone and secondary aerosols, which are a threat to human health (Wheeler *et al*., 2013).

The literature indicates that short-term exposure to high levels of BTEX can cause symptoms such as eye, nose and throat irritation, headaches, nausea and vomiting, dizziness, and the exacerbation of asthma symptoms (Danish EPA, 2016; Nielsen *et al*., 2008; Han & Naeher, 2006). Long-term, chronic exposure at high levels can increase the risk of liver damage, kidney damage, cancer, and central nervous system damage (ATSDR, 2007; IARC, 2004). Long-term exposure to low concentrations of benzene may increase the incidence of leukaemia and aplastic anaemia in humans (ATSDR, 2018; Wheeler *et al*., 2013). Long-term exposure to high concentrations of benzene is associated with the development of leukaemia and hematopoietic cancers, and in consequence this chemical is considered a human carcinogen (ATSDR, 2007; IARC, 2004). Benzene is the most toxic compound within the BTEX due to its haematotoxic, neurotoxic, leukemogenic and carcinogenic effects (Danish EPA, 2016; Nielsen *et al*., 2008; ATSDR, 2007). Toluene and xylene are respiratory tract irritants that may have adverse effects on the respiratory and cardiovascular systems (Cheng *et al*., 2017, Wheeler *et al*., 2013). Short-term exposure to toluene and xylene may result in eye irritation and headaches. Long-term exposure to toluene and xylene may result in aggravated asthma, emphysema, pneumonia, and bronchitis. Long-term exposure may also lead to emphysema, chronic bronchitis and arteriosclerosis (ATSDR, 2007, 2018; IARC, 2004). Ethylbenzene is also a skin and respiratory tract irritant and can cause severe eye irritation. Ethylbenzene is categorised as a possible group 2B human carcinogen (IARC, 2013). All these chemicals are emitted during the burning of firewood for domestic use.

Domestic burning of firewood is one of the major sources of BTEX in rural residential areas (Cheng *et al*., 2017; Annesi-Maesano *et al*., 2013; Evtyugina *et al*., 2013). Everyday exposure to BTEX emitted in the firewood smoke may contribute to an increasing prevalence of associated diseases (Bruce *et al*., 2000). Health impacts depend on a range of parameters related to fuel properties, the type of stoves used, human exposure, fuel moisture, burning rate, ventilation and cooking behaviour. Risk assessments relating to these toxic pollutants have been conducted in various countries as part of a regulatory decision-making process to combat indoor air pollution. In a risk assessment, the extent to which a population is or may be exposed to a certain chemical is determined, and the extent of exposure is considered in relation to the type and degree of hazard posed by the chemical, thereby permitting an estimate of the potential health risk due to that chemical for the population involved. Previous studies in this field focused on industries and outdoor environments: for example, Morakinyo *et al*. (2017) studied exposure to BTX in an industrial area, and Thabethe *et al*. (2014) studied health risks posed by exposure to particulate matter. According to Wheeler *et al*. (2013) and Moradi *et al*. (2019), concentrations of BTEX are higher indoors than in the ambient atmosphere. Nevertheless, only a few studies in South Africa have focused on exposure to BTEX in the indoor environment. Masekameni *et al*. (2019) studied the emission of BTEX from the household burning of coal, while Muller *et al*. (2003) focused on emissions from the domestic use of kerosene. The study reported on in the present study adapted the environmental health risk assessment to quantify the risk associated with BTEX arising from the burning of household firewood.

6.2 Materials and methods

The methods adopted in the current study build on previous publications by Semenya and Machete (2018; 2019a; 2019b). In the later publications, surveys, observations and ethnobotanical meta-analysis were used to study the priority firewood plant species used by Bapedi households in Senwabarwana Villages, namely *Mushu*, *Moretshe*, *Mohwiliri*, *Mokgwa* and *Motswiri*. The current study therefore burnt 1kg of each priority firewood species for experimentation and collected sample of each of the four selected VOCs (benzene, toluene, ethylbenzene and xylene) with the use of active sampling methods. Tedlar bags were used in a kitchen-simulated laboratory room of 4.5 m2 floor area; 2.4 m floor-to-ceiling height. The bag was connected to a pump and air was sampled at a flow rate of 5 mL/min for one hour, as recommended by SKC (2018). The residents estimated the cooking time to be one hour. VOCs monitoring over a five-day period in spring (September 2018) were considered adequate since assessment considered acute rather than chronic exposure (USEPA, 1996). The VOC bags were analysed at an accredited laboratory (SKC South Africa Chemtech Laboratory, accreditation number T0361) using the NIOSH 2549 analytical method. Indoor air pollutants are mainly ingested through inhalation therefore intake via skin and the digestive system can be ignored (USEPA, 2014). Thus, this study ignored other pathway of pollutants and focused on intake through respiratory tract.

The results of the experiment (VOCs) were descriptively and statistically analysed and presented through frequency tables and figures.

6.3 Results and discussion

The results are presented according to the three IEHRA stages, namely toxicity assessment, exposure assessment and risk characterisation.

6.3.1 Toxicity assessment

Firewood is the dominant fuel type used in the study area. No other indoor sources of BTEX emission such as glues, paints, furniture wax, detergents, upholstery fabrics, carpets, adhesives, varnishes, vinyl floors, cleaning chemicals, air fresheners or cosmetics were observed in the kitchens. The method of using an open fire under a tripod for cooking (figure 6.1(a and b) was replicated. The use of an advanced firewood stove with a chimney could reduce the levels of emissions released into the kitchen (Wu *et al.*, 2017). However, community members in Senwabarwana use a tripod over an open fire, which releases smoke into the kitchen. Black soot was observed on the walls of some kitchens. This exposes the person responsible for cooking, along with family members and/or neighbours, to pollutants in the smoke, which might have negative effects on their health.

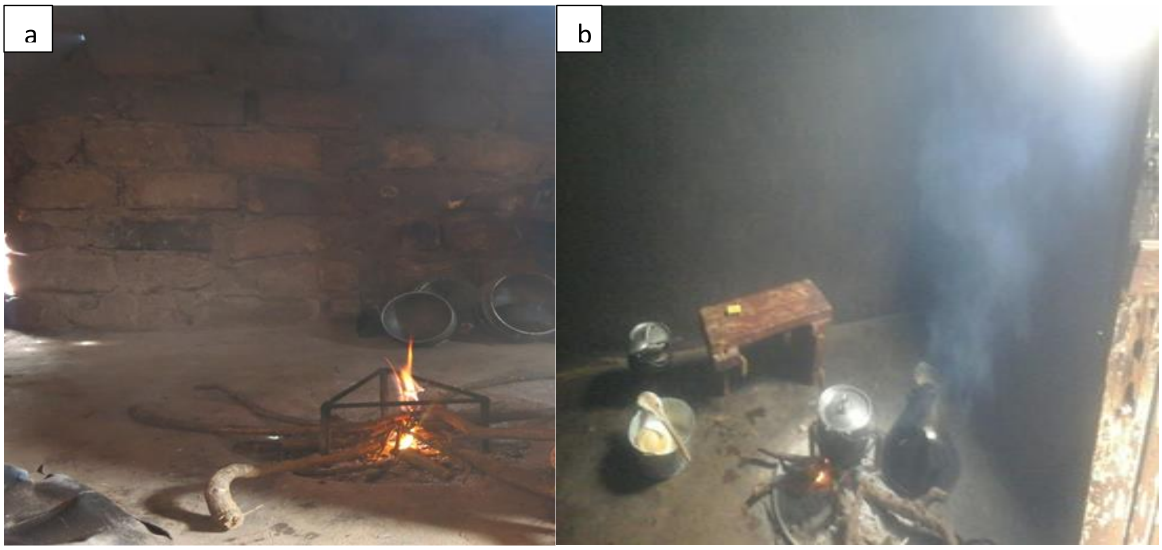


Figure 6.1 Tripod over an open fire

During site visits and observation of household kitchens, none of the kitchens was found to contain non-firewood sources of BTEX such as glues, paints, furniture wax, detergents, upholstery fabrics, carpets, adhesives, varnishes, vinyl floors, cleaning chemicals, air fresheners or cosmetics. Thus, except for potential ambient sources of BTEX, the domestic sources of BTEX listed above were excluded as potential sources of the BTEX found in these kitchens. It was observed that all the respondents used firewood to make an open fire for cooking, and this practice has the potential to cause adverse health effects through the inhalation of smoke released from combustion. The process of hazard identification revealed that BTEX are pollutants released during the burning of firewood. Adverse health effects associated with the use of firewood were reported and are discussed below.

Reported health effects

Table 6.1 presents common health challenges associated with the smoke from the combustion of firewood.

Table 6.1 Ill health conditions reported by households (N=69)

Ill-health conditions	**Number of respondents**	**Percentage (%)**
Asthma	8	12
Pneumonia	1	1
Tuberculosis (TB)	8	12
Eye problems	23	33
Headache	32	46
Heart problems	6	9
Cancer	2	3
Stroke	3	4

Forty-six per cent of respondents self-reported headaches more frequently, followed by eye problems (33%) sore, red and teary eyes; the burning of biomass fuel produces smoke that irritates the eyes (Pokhrel *et al*., 2010). According to the International Agency for Research on Cancer (IARC) (2004), VOCs are irritants to the eyes and respiratory tract. Although relying on self-reported diseases may make the study unreliable, a case-control study of indoor cooking smoke exposure and cataract prevalence in Nepal and India found that the use of solid fuel in unfuelled indoor stoves is associated with an increased risk of eye problems with cataract development in women (Pokhrel *et al*., 2005). There is therefore a correlation of findings between the latter study and the current study. In many households, everyday exposure to air pollution may contribute to an increasing prevalence of asthma and cancer (Bruce *et al*., 2000). In this study, twelve per cent of respondents self-reported asthma, and three per cent self-reported cancer. Pneumonia was reported by only one per cent, whereas 9% reported heart problems and four per cent reported incidents of strokes.

Literature indicates that short-term exposure to high levels of the BTEX can cause symptoms like eye, nose and throat irritation, headaches, nausea and vomiting, dizziness, and the worsening of asthma symptoms. Scientific studies suggest that long-term, chronic exposure at high levels can cause an increased risk of liver damage, kidney damage, cancer, and central nervous system damage. Based on the sicknesses reported BTEX were then identified as hazards.

6.3.2 Exposure assessment

Table 6.2 presents the detected concentrations of BTEX during the burning of the wood of each tree species. As discussed earlier, these are the concentrations that the community of Senwabarwana is exposed to during the indoor burning of firewood.

Table 6.2 Exposure concentrations of BTEX per selected plant species (µg/m^3)

Chemicals	**Concentration of BTEX per plant species (µg/m3)**					**Inhalation Acute Reference Exposure level (µg/m3) (OEHHA, 2019)**
	Mushu	**Moretshe**	**Motswiri**	**Mokgwa**	**Mohweleri**	
Benzene	41.0	13.3	0.01	0.01	0.01	27
Toluene	22.7	8.7	0.01	Not detected	Not detected	5000
Ethylbenzene	2.2	0.01	Not detected	Not detected	Not detected	Not found
Xylene	0.01	0.01	Not detected	Not detected	Not detected	22000

The lowest benzene concentration was detected in *Motswiri*, *Mokgwa* and *Mohwliri*. A high concentration of toluene was emitted by the burning of *Mushu*, followed by *Moretshe*, while low concentrations were obtained from burning *Motswiri*, *Mokgwa* and *Mohwliri*. Ethylbenzene and xylene were emitted from the burning of *Mushu* only and were not detected in the other firewood species. Higher concentrations could be expected during prolonged continuous monitoring as well as in the winter months, when the area becomes prone to pollution accumulation due to climatic conditions.

Few jurisdictions have developed indoor air guidelines. No indoor air guidelines were found for BTEX components in South Africa, and so relevant guidelines from anywhere in the world could be used; for the purposes of the study, the acute reference exposure level (REL) from California was adopted (OEHHA, 2019). Average exposure time for acute RELs is 1 hour. REL assumes that toxic effects will not occur until a threshold dose is exceeded (NRC, 1994).

According to the World Health Organisation (2010), there is no safe level of exposure to benzene. Even though the REL from California was used in the study, it is assumed that benzene has a negative health effect at all levels of exposure. Only *Mushu* exceeded the acute benzene REL from California, while *Motswiri*, *Moretshe*, *Mokgwa* and *Mohweleri* did not exceed the given REL. No toluene was detected as a result of the burning of *Mokgwa* and *Mohweleri*, while the burning of *Motswiri*, *Moretshe* and *Mushu* yielded concentrations lower than the recommended REL of toluene. No ethylbenzene or xylene was detected associated with the use of *Motswiri*, *Mokgwa* or *Mohweleri.* Acute REL for was not found. Xylene levels lower than the REL value were associated with the use of both *Mushu* and *Moretshe*.

6.3.3 Risk assessment

This step combines the information from the two previous steps to provide an indication of the nature and expected frequency of adverse health effects in exposed populations. The fundamental assumption of the sampling strategy is that measured concentrations represent maximum concentrations to which all individuals could be exposed in the kitchen (USEPA, 2014). If this assumption is true, then the risk of developing adverse health conditions due to the presence of the VOCs studied can be assessed as negligible. This holds for all the VOCs in the study. Table 6.3 presents both the hazard quotient (HQ) and hazard index (HI) of non-carcinogenic pollutants (TEX) per plant species. HQ and HI indicate the presence or absence of adverse health effects due to exposure.

Table 6.3. Hazard quotient (HQ) and hazard index (HI) of TEX for each plant species in the study

Chemicals	**HQ of BTEX for each plant species**				
	Mushu	**Moretshe**	**Motswiri**	**Mokgwa**	**Mohweleri**
Toluene	0.004	0.002	0.000	Not detected	Not detected
Xylene	0.000	0.000	Not detected	Not detected	Not detected
HI	0.004	0.002	0.000	0.000	0.000

HQ is less than 0.1, indicating that no hazards are associated with the use of any of the five-plant species used for firewood in Senwabarwana, even in the case of sensitive individuals. HI is also less than 1, indicating no risk associated with the use of any of the five-plant species used for firewood in Senwabarwana. This hazard quotient and index might be attributable to the opening of the windows and doors during cooking.

6.4 Conclusion

The aim of the study under discussion was to quantify environmental health risks due to exposure to BTEX emitted from the burning of the wood of five firewood tree species. An integrated environmental health risk assessment (IEHRA) framework was used to collect and analyse data. The results of the IEHRA show that firewood was burnt in poorly ventilated kitchens under a tripod stand. The use of the five identified species was shown to pose no health risk to the members of the Senwabarwana community (expect for Benzene ans ethylbenzene). When assessing the risk to children in this type of residential setting, the risk assessor should keep in mind that exposure parameters, specifically those related to activity patterns (e.g., exposure time, frequency, and duration) may be different for children and adults at the same site. Children may spend more time near the source of contamination than adults, and exposure time and/or exposure frequency values for children would therefore be higher than those recorded for adults living in the same location. Regarding indoor vapour intrusion from the subsurface, very young children might have much higher exposure because of spending considerable time indoors.

Because the study entailed monitoring volatile organic pollutants over a limited period, it was not possible to estimate risks over longer periods of exposure (chronic health effects); nor was it possible to show seasonal fluctuations. Owing to the absence of annual exposure values, a cancer risk was not calculated. However, the acute results have indicated that there are no risks associated with the use of the types of firewood utilised in Senwabarwana. There is however no safe level exposure to benzene meaning clean methods of combusting firewood should still be considered. The use of trees which emits high concetrantions of pollutants such as Mushu should be encouraged to be burnt in a wood gasification stove .

References

Annesi-Maesano, I., Baiz, N., Banerjee, S., Rudani, P. & Rive, S. on behalf of the SINOPHONIE group. (2013). Indoor air quality and sources in schools and related health effects. Journal of Toxicology and Environmental Health, 16(8), 491–550.

ATSDR (Agency for Toxic Substance and Disease Registry). (2007). The toxic guide. Accessed from https://www.atsdr.cdc.gov/substances/toxsubstance.asp?toxid=14 on 3 October 2018.

ATSDR (Agency for Toxic Substance and Disease Registry). (2018). Minimal risk levels. Accessed from https://www.atsdr.cdc.gov/mrls/pdfs/atsdr_mrls.pdf on 5 October 2018.

Bruce, N., Perez-Padilla, R. & Albalak, R. (2000). Indoor air pollution in developing countries: A major environmental and public health challenge. Bulletin of the World Health Organization, 78 (2000), 1078–1092.

Caravanos, J., Kevin, C., Bret, E., Landrigan, P.J. & Fuller, R. (2013). The burden of disease from pediatric lead exposure at hazardous waste sites. *Environmental Research*, 120 (2013), 119–125.

Cheng, Z., Li, B., Yu, W., Wang, H., Zhang, T. & Bu, Z. (2017). Risk assessment of inhalation exposure to VOCs in dwellings in Chongqing, China. Healthy buildings 2017 Europe. ISBN: 978-83-7947-232-1.

Clark, L.M., Reynolds, S.J., Burch, J.B., Conway, S., Bachand, A.M., & Peel, J.L. (2010). Indoor air pollution, cookstove quality, and housing characteristics in two Honduran communities. *Environmental Research*, 110, 12–18.

Danish EPA (Danish Environmental Protection Agency). (2016). Survey and risk assessment of toluene and other neurotoxic substances in children's rooms. Accessed from https://www2.mst.dk/Udgiv/publications/2016/02/978-87-93435-42-1.pdf on 17 March 2018.

Evtyugina, M., Alves, C.A., Calvo, T., Nunes, L., Tarelho, M., Duarte, D. & Prozil, S.O. (2013). Emission of volatile organic compounds from the residential combustion of Pyrenean oak and black poplar. *International Journal of Environmental and Ecological Engineering*, 7(6).

Frazzoli, C., Orisakwe, O. E., Dragone, R., & Mantovani, A. (2010). Diagnostic health risk assessment of electronic waste on the general population in developing countries' scenarios. *Environmental Impact Assessment Review*, 30, 388-399.

Gawrys, M., Fastyn, P., Gawłowski, J., Gierczak, T. & Niedzielski, J. (2001) Prevention of water vapour adsorption by carbon molecular sieves in sampling humid gases. *Journal of Chromatography A*, 933 (1–2), 107–116.

Guo, H., Lee, S.C., Chan, L.Y. & Li, W.M. (2003). Risk assessment of exposure to volatile organic compounds in different indoor environments. *Environmental Research*, 94, 57–66.

Han, X., & Naeher, L.P. (2006). A review of traffic-related air pollution exposure assessment studies in the developing world. *Environmental International*, 32(1), 106–120.

IARC (International Agency for Research on Cancer). (2013). Carcinogenic to humans. Accessed from http://monographics.iarc.fr/ENG/Classification/index.php on 27 September 2018.

IARC (International Agency for Research on Cancer). (2004). Overall evaluation of carcinogenicity to humans. IARC monographs. Accessed from http://www.monographs.iarc.fr/ENG/Classification/latest_classif.php on 27 September 2018.

Janis, S. (2001). Landfill sites: Risk of adverse birth outcomes. Practice Nurse, 1, 66.

Joon, V., Kumar, K., Bhattacharya, M. & Chandra, A. (2014). Non-invasive measurements of carbon monoxide in rural Indian women exposed to different cooking fuel smoke. Aerosol and *Air Quality Research*, 14, 1789-1787.

Keller, G. (2014). Statistics for Management and Economics. 10th Ed. Canada: Cengage Learning

Kapwata, T., Language, B., Piketh, S. & Wright, C.Y. (2018). Variation of indoor particulate matter concentrations and association with indoor/outdoor temperature: A case study in rural Limpopo, South Africa. *Atmosphere*, 9, 124. DOI: 10.3390/atmos9040124.

Lemly, A.D. (1996) Evaluation of the hazard quotient method for risk assessment of selenium. *Ecotoxicology and Environmental Safety*, 35(2), 156–162.

Machete, F. (2017). Environmental health risks associated with e-waste exposure in Badplaas, Carolina and Elukwatini landfills, Republic of South Africa. *African Journal of Science, Technology, Innovation and Development*. DOI: 10.1080/20421338.2017.1355602.

Machete, F & Shale, K (2015) Classification of unregulated landfills by waste stream analysis method, a case of Chief Albert Luthuli Municipality, South Africa. A*frican Journal of Science, Technology, Innovation and Development,* 7(6), 446-452.

Masekameni, M.D., Moolla, R., Gulumian, M. & Brouwer, D. (2019). Risk Assessment of Benzene, Toluene, Ethyl Benzene and Xylene Concentrations from the combustion of coal in a controlled laboratory environment. *International Journal of Environmental Research and Public Health*, 16(95).

Mitchell, E.J.S., Lea-Langton, A.R., Jones, J.M., Williams, A., Layden, P. & Johnson, R. (2016). The impact of fuel properties on the emissions from the combustion of biomass and other solid fuels in a fixed bed domestic stove. *Fuel Processing Technology*, 142, 115-123.

Moradi, M., Hopke, P., Hadei, M., Eslami, A., Rastkari, Naghdali, Z., Kermani, M., Emam, B., Farhadi, M. & Shahsavani, A. (2019). Exposure to BTEX in beauty salons: biomonitoring, urinary excretion, clinical symptoms, and health risk assessments. *Environ Monit Assess*, 191-286.

Morakinyo, O.M., Mokgobu, M.I., Mukhola, M.S. & Engelbrecht, J.C. (2017). Health risk assessment of exposure to ambient concentrations of benzene, toluene and xylene in Pretoria West, South Africa. *African Journal of Science, Technology, Innovation and Development*, 9(4), 489–496.

Muller, E., Diab, R.D., Binedell, M. & Hounsome, R. (2003). Health risk assessment of kerosene usage in an informal settlement in Durban, South Africa. *Atmospheric Environment,* 37, 2015–2022.

Nielsen, E., Dybdahl, M. & Larsen, P.B. (2008). Health effects assessment of exposure to particles from wood smoke. Danish Ministry of the Environment: Environmental Protection Agency. Accessed from http://www.orbit.dtu.dk/.../Health_effects_assessment_of_exposure_to_particles_from_wood smoke on 19 May 2018.

NRC (National Research Council). (1994). Science and Judgment in Risk Assessment. USA: National Academy Press.

OEHHA (California Office of Environmental Health Hazard Assessment). (2019). Acute, 8-hour and Chronic Reference Exposure Level (REL) summary uploaded 4 November 2019. Accessed from http://oehha.ca.gov/generalinfo on 20 December 2019.

Olave, R.J., Forbes, E.G.A., Johnson, C.R. & Relf, J. (2017). Particulate and gaseous emissions from different wood fuels during combustion in a small-scale biomass heating system. *Atmospheric Environment*, 157, 49–58.

Oosthuizen, M.A., Wright, C.Y., Matooane, M. & Phala, N. (2015). Human health risk assessment of airborne metals to a potentially exposed community: A screening exercise. *The Clean Air Journal*, 25(1), 51–57.

Parajuli, I., Lee, H. & Shrestha, K.R. (2016). Indoor air quality and ventilation assessment of rural mountainous households of Nepal. *International Journal of Sustainable Built Environment*, 5, 301-311.

Paustenbach, D.J. (1989). The risk assessment of environmental and human health hazards: A textbook of case studies. John Wiley & Sons, USA.

Pokhrel, A.K., Smith, K.R., Khalakdina, A., Deuja, A. & Bates, M.N. (2005). Case-control study of indoor cooking smoke exposure and cataract in Nepal and India. *Int J Epidemiol*, 34, 702–708.

Semenya, K. & Machete. F. (2019). Integrated Environmental Health Risk Assessment Framework for Firewood-Induced Indoor Air Pollution. *WIT Transactions on Ecology and the Environment*, 236, 179–190.

SKC. (2018). Step by step guide (An introduction to air sampling). Accessed from http://www.skcltd.com on 10 November 2017.

Slack, R.J., Gronow, J.R. & Voulvoulis, N. (2005). Household hazardous waste in municipal landfills: Contaminants in Leachate. *Science of the Total Environment*, 337, 1(3), 119–137.

Thabethe, N.D.L., Engelbrecht, J.C., Wright, C.Y. & Oosthuizen, M.A. (2014). Human health risks posed by exposure to PM10 for four life stages in a low socio-economic community in South Africa. *Pan African Medical Journal*, 18(206).

USEPA (United States Environmental Protection Agency). (2009). Risk Assessment Guidance for Superfund (RAGS); Volume, I: Human Health Evaluation Manual; Part F, Supplemental Guidance for Inhalation Risk Assessment: Final; USEPA: Washington, DC, USA. Accessed from https://www.epa.gov/sites/production/files/2015-09/documents/partf_200901_final.pdf on 26 September 2018

USEPA (United States Environmental Protection Agency). (2014). Framework for Human Health Risk Assessment to Inform Decision Making. Accessed from https://www.epa.gov/sites/production/files/2014-12/.../hhra-framework-final-2014.pdf on 26 September 2018.

USEPA (United States Environmental Protection Agency). (2018). Indoor Air Quality. Technical overview of Volatile Organic Compounds. Accessed from:

https://www.epa.gov/indoor-air-quality-iaq/technical-overview-volatile-organic-compounds on 26 September 2018

Wheeler, A.J., Wong, S.L., Khoury, C. & Zhu, J. (2013). Predictors of indoor BTEX in Canadian residences. Component of Statistics Canada Catalogue no. 82-003-X, Health Reports, 24 (5), 11–17.

Williams, A., Jones, J.M., Ma, L. & Pourkashanian, M. (2012). Pollutants from the combustion of solid biomass fuels. *Progress in Energy and Combustion Science*, 38, 113-137

Woolfenden, E. (2010). Sorbent-based sampling methods for volatile and semi-volatile organic compounds in air, part 1: sorbent-based air monitoring options. *Journal of Chromatography A*, 1217 (16), 2674–2684.

World Health Organisation. (2010). WHO guidelines for indoor air quality: selected pollutants. WHO Press, Geneva, Switzerland.

Wu, W., Zhu, H., Qu, Y. & Xu, K. (2017). Regional disparities in emissions of rural household energy consumption: A case study of Northwest China. *Sustainability*, 9(76), 1–17.

CHAPTER 7: CONCLUSION

7.1 Introduction

In this chapter, important findings and a synthesis of the research results of the study are summarised. Conclusions and contributions of the study to the environmental sciences and the air quality field are highlighted. Future research focus areas emerging from the limitations and delimitations of this study are also outlined.

7.2 Summary of results

This was a multidisciplinary and contemporary research study in the energy, indigenous knowledge, air pollution, botany and public health fields which was aimed at assessing environmental health risks associated with firewood induced volatile organic compounds in senwabarwana villages. This study integrated observations, ethnobotanical meta-analysis and experimental into one comprehensive integrated environmental health risk assessment framework to assess the risks associated with exposure to volatile organic compounds from firewood combustion. Basic information about firewood usage, socio-economic dynamics and perceived health problems related to volatile organic compounds was collected using a structured questionnaire. The Vac-U-Chamber was used to sample the air.

The results show that firewood is extensively used in poorly ventilated kitchens for cooking and home heating in Senwabarwana villages. Ten priority firewood plant species are frequently used in the study area, namely Mohweleri (*Combretum apiculatum*), Moretshe (*Dichrostachys cinera*), Motswiri (*Combretum imberbe*), Mokgwa (*Acacia burkei*), Mushu (*Acacia tortilis*), Motshe (*Cussonia paniculate*), Mokata (*Combretum hereroense*), Mphata (*Lonchocarpus capassa*), Mokgalo (*Ziziphus mucronate*) and Mogwana (*Grewia monticola*) in their order of preference.

The results also indicated thirteen common reasons or factors that influence the choice of firewood plant species by households, the main four being: (i) the embers formed during combustion, (ii) heat value, (iii) low ash content and (iv) availability of the firewood plant species. Further analysis revealed several several uses and ranking thereof, including reviewing the national status and legal profile of each identified plant species. The study found that most of the firewood species used in Senwabarwana Village were indigenous. Major drivers of firewood use are household income, educational status of breadwinners, family sizes, and place of residence, fuel affordability and accessibility, among others.

Concentrations of benzene, toluene, ethylbenzene and xylene per plant species were studied in order to assess the risk exposed to the Senwabarwana community. Literature indicates that these pollutants have several health effects associated with acute exposure such as eye, nose and throat irritation, headaches, dizziness, nausea and vomiting. Both hazard quotient and hazard index were found to be less than one indicating no risk exists with the use of plant species used for firewood in Senwabarwana even to sensitive individuals. The risk of developing health effects due to the presence of the studied volatile organic compounds can be assessed as negligible.

In conclusion, there is a complex relationship between household energy use and the economic status of a community. While the literature indicates that, firewood can nowadays be considered a relatively clean-burning fuel given the appropriate equipment this was not the case in Senwabarwana as firewood is burned in an open, poorly ventilated kitchens. The families in these commnuties cannot afford new stoves due to their income which is below the poverty line. It is therefore recommended that modern processing and usage technology such as micro-gasifier stoves which allow for cleaner firewood combustion as indicated by literature be introduced to this community with the assistance of the municipality. Though the risk of the pollutants emitted by combustion of firewood can be neglected, replacing open fires with micro-gasifier stoves could reduce firewood consumption effectively. The wood that emits less concentration of pollutants such as Motswiri, Mohwiliri and Mokgwa be used for firemaking.

7.3 Knowledge revealed by this study (Contribution of the study)

Like any previous studies, this research considers that air pollution is a major problem which needs urgent attention from both researchers and government officials. However, this study demarcates from other studies by the fact that its focus is on the use of firewood in household as a source of energy. The risks associated with the use of firewood as a source of energy has not been sufficiently investigated in the South African context. This study contributes in understanding the dynamics of firewood energy use in South Africa and other African countries.

Although a great amount of literature exists on the factors that influence fuelwood consumption among households especially in developing countries, there appears to be inconsistence in their findings and conclusions. Findings and conclusions of a study in a certain area cannot therefore be used to generalize another area due to the differences in socio-economic dynamics. It was therefore necessary to explore the factors that influences the use of firewood in Senwabarwana (see section 4.3.3).

Furthermore, several studies have been conducted on the domestic use of plants, however, there is a lack of information on the types of firewood used. This study revealed the names of woods used for fire making and the reasons why certain types of firewood are preferred over others (see section 5.3.1). The results also revealed common reasons or factors that determine the choice of firewood plant species by households (see section 5.3.2). Ultimately, in addition to types of firewood used the study explored volatile organic compounds during the combustion of firewood (6.3.2). This was to close the gap found in the literature on indoor air pollutants since only few studies in South Africa have focused on the exposure to BTEX in the indoor environment and most focus was on Kerosene and Coal. Firewood is used for energy needs with little information on harvesting of the plants including the criteria used to select plants used for firemaking. Unlike the western knowledge of how wood is selected, the indigenous knowledge is not documented. It was therefore necessary to explore indigenous knowledge and practices on the indigenous plants for firewood making. Unless this knowledge is recorded in time it is bound to be lost for ever.

Despite the health effects caused by volatile organic compounds, there has been a gap on the indoor volatile organic compound caused by these chemicals particulary in households where firewood is used for cooking and space heating. This study deemed it necessary to study these pollutants and close the existing gap in the literature (see section 6.3.3).

The results of this study contribute to the body of knowledge on cooking energy patterns at the household level and, more specifically, to understanding why households mix various fuel sources even when there is access to cleaner fuel. The results of this study may also contribute to Africa agenda 2030 and 2063 in achieving its goal of enhancing international cooperation to facilitate access to clean energy research and technology.

While the study was based on a small community in South Africa the author believes that the same trends could be found in other places around the country and worldwide, it could help to improve longevity and the quality of lives in Senwabarwana and African communities using firewood for energy needs. This knowledge is also critical for other developing countries that may face the same conflict of interest as South Africa.

7.4 Recommendations for Further studies

Based on the limitations identified in this study the following are recommended:

- Conduct similar studies in other provinces of the country to gain a national understanding of the factors that determine the use of firewood. Also document the types of wood used for fire making in those provinces.
- Consider conducting further studies with a bigger sample size. The spectrum of pollutants monitored should ideally be enlarged to include sulphur dioxide, nitrogen dioxide, carbon dioxide, other greenhouse gases, particulates and other VOCs. In addition, outdoor air quality monitoring of the same pollutants would be useful, as would studies on the ventilation of the houses in Senwabarwana.
- Conduct further research on the psychosocial and behavioural issues related to the use of firewood.
- Conduct epidemiological studies for direct determinants of health and disease conditions in Senwabarwana.
- Conduct studies on air quality over a longer period that would allow an estimation of the risk of cancer effects. An assessment of the risks posed by exposure to other pollutants should be included.

Annexure 1: Questionnaire

Kindly complete the following demographics about (respondent)

1. Gender	
2. Age	
3. Total monthly income	
4. Family size	
5. Employment status	
6. Highest level of education obtained	
7. Race	
8. GP Coordinates	

On a scale of 1 to 5, (5 being the most used and 1 being the least used) rank the following energy sources as used in your household.

	Cooking	Space heating	Water heating	Reason
9. Firewood				
10. Electricity				
11. Dung				
12. LPGas				
13. Other (specify)				

14. What is your preferred energy source for cooking in your household (mention only one energy source) and why?

…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

15. What is your preferred energy source for water heating in your household (mention only one energy source) and why?

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…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

16. What is your preferred energy source for space heating in your household (mention only one energy source) and why?

…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

Which situation is applicable in your household (select only one applicable answer?)

	Daily	Once a week	Monthly	Other (specify)
17. How frequent does your household make fire for cooking?				
18. How frequent does your household make fire for space heating?				
19. How frequent does your household make fire for water heating?				
20. How frequent does, your household collect wood?				

21. How do you make fire (discuss the step-by-step process of making fire)?
………………………………………………………………………………………………
………………………………………………………………………………………………
………………………………………………………………………………………………
………………………………………………………………………………………………

22. According to your knowledge, which common types of trees does your household normally used for firewood (list at least five)

Tree name	Reasons for tree preference/use
a.	
b.	
c.	
d.	
e.	
f.	
g.	

23. Where does your household commonly find or harvest firewood (name a location or name of a physical facility/place)
……………………………………………...

24. What is the estimated distance (km for single trip) that your household members travel to collect firewood?
…………………….……………………………………………………………………….

25. How much of wood (weight) do you use per week?
………………………………………………………………………………………………..

How would you rate your household energy use situation (use the scale below)

	Strongly agree	agree	Disagree	Strongly disagree
26. Live trees from the nearest forest are cut and dried at my household				
27. Dry wood is collected from the nearest forest by household				

28. wood is collected by head log from the nearest forest				
29. wood is collected by donkey cart from the nearest forest				
30. wood is collected by head log from the nearest forest				
31. wood is collected by vehicle from the nearest forest				
32. wood is bought from firewood suppliers				

Do you or anyone in your household suffer or suffered from the following? Please tick either yes or no.

Diseases	Yes	No
33. Asthma		
34. Pneumonia		
35. TB		
36. Eye problem		
37. Headache		
38. Heart problems		
39. Lung cancer		
40. Stroke		
41. Lung disease		
42. Other (specify)		

CHECKLIST

	Inputs
43. Connection to electricity grid	
44. Kitchen size (m^2) floor area	
45. Total area of windows (m^2)	
46. Is there a door? What is the size (m^2)	
47. Direction of the kitchen door (North, south, East or West)	
48. Type of material used for kitchen walls (brick, corrugated iron etc.)	
49. Height (kitchen floor to ceiling/roof)	
50. Fire area (stove, open or etc.)	

ANNEXURE 2: CONSENT FORM

PARTICIPANT INFORMATION SHEET

Ethics clearance reference number: 001/2016
Research permission reference number:001/2016

17 December 2017

Title: Investigation of household firewood volatile organic pollutants and environmental health risks: The case study of Thorp Village, Limpopo Province, RSA

Dear Prospective Participant

My name is Khomotso Semenya and I am doing research with Dr F Machete, a Senior Lecturer in the Department of Environmental Sciences towards a PhD at the University of South Africa. We are inviting you to participate in a study entitled Investigation of household firewood induced criteria pollutants and environmental health.

WHAT IS THE PURPOSE OF THE STUDY?

I am conducting this research to find out:

- The types of fuelwood you are using and the reasons for using certain fuelwood.
- How you make fire.
- If you are aware of any health and environmental issues that emanate from using fuelwood.

WHY AM I BEING INVITED TO PARTICIPATE?

I obtained your details form Koena Semono who is the residence of this area. She identified you because you are using fuelwood and you might have information required for this project to be successful. About 50 participants are required to participate in this study.

WHAT IS THE NATURE OF MY PARTICIPATION IN THIS STUDY?

You are requested to answer questions in form of a questionnaire (see the attached). This will take 20 minutes to complete.

CAN I WITHDRAW FROM THIS STUDY EVEN AFTER HAVING AGREED TO PARTICIPATE?

Participating in this study is voluntary and you are under no obligation to consent to participation. If you do decide to take part, you will be given this information sheet to keep and be asked to sign a written consent form. You are free to withdraw at any time and without giving a reason. However, be informed that once the questionnaire is submitted it might be difficult to retrieve it.

WHAT ARE THE POTENTIAL BENEFITS OF TAKING PART IN THIS STUDY?

You will be given the results of the study and the recommendation might benefit you and your community.

ARE THERE ANY NEGATIVE CONSEQUENCES FOR ME IF I PARTICIPATE IN THE RESEARCH PROJECT?

There are no risks.

WILL THE INFORMATION THAT I CONVEY TO THE RESEARCHER AND MY IDENTITY BE KEPT CONFIDENTIAL?

You have the right to insist that your name be not used anywhere and that no one, apart from the researcher and identified members of the research team, will know about your involvement in this research. Your answers will be given a code number or a pseudonym and you will be referred to in this way in the data, any publications, or other research reporting methods such as conference proceedings.

Only my supervisor and I will have access to the data. However, this data may be used for other purposes, such as a research report, journal articles and/or conference proceedings. Your names will not be used.

HOW WILL THE RESEARCHER(S) PROTECT THE SECURITY OF DATA?

The researcher will store hard copies of your answers for a period of five years in a locked cupboard/filing cabinet at UNISA for future research or academic purposes; electronic information will be stored on a password-protected computer. Future use of the stored data will be subject to further Research Ethics Review and approval if applicable. After five years, questionnaires copies will be shredded.

WILL I RECEIVE PAYMENT OR ANY INCENTIVES FOR PARTICIPATING IN THIS STUDY?

Your participation is voluntarily and there is no payment or incentives.

HAS THE STUDY RECEIVED ETHICS APPROVAL?

This study has received written approval from the Research Ethics Review Committee of the College of Agriculture and Environmental Sciences, Unisa. A copy of the approval letter is attached.

HOW WILL I BE INFORMED OF THE FINDINGS/RESULTS OF THE RESEARCH?

If you would like to be informed of the final research findings, please contact Khomotso Semenya on 0824370034/ 0114712138 or email address: semenk@unisa.ac.za. The findings are accessible for January 2018. Should you require any further information or want to contact the researcher about any aspect of this study, please contact Khomotso Semenya on the numbers indicated above.

Should you have concerns about the way in which the research has been conducted, you may contact Dr F Machete on 011 471 2704, or on email address: machef@unisa.ac.za. Contact the research ethics chairperson of the CAES General Ethics Review Committee, Prof EL Kempen on 011-471-2241 or kempeel@unisa.ac.za if you have any ethical concerns.
Thank you for taking time to read this information sheet and for participating in this study.

Thank you.

Khomotso Semenya

CONSENT TO PARTICIPATE IN THIS STUDY

I, __________________ (participant name), confirm that the person asking my consent to take part in this research has told me about the nature, procedure, potential benefits and anticipated inconvenience of participation.

I have read (or had explained to me) and understood the study as explained in the information sheet.

I have had sufficient opportunity to ask questions and am prepared to participate in the study.

I understand that my participation is voluntary and that I am free to withdraw at any time without penalty (if applicable).

I am aware that the findings of this study will be processed into a research report, journal publications and/or conference proceedings, but that my participation will be kept confidential unless otherwise specified.

I agree to the recording of the <insert specific data collection method>.

I have received a signed copy of the informed consent agreement.

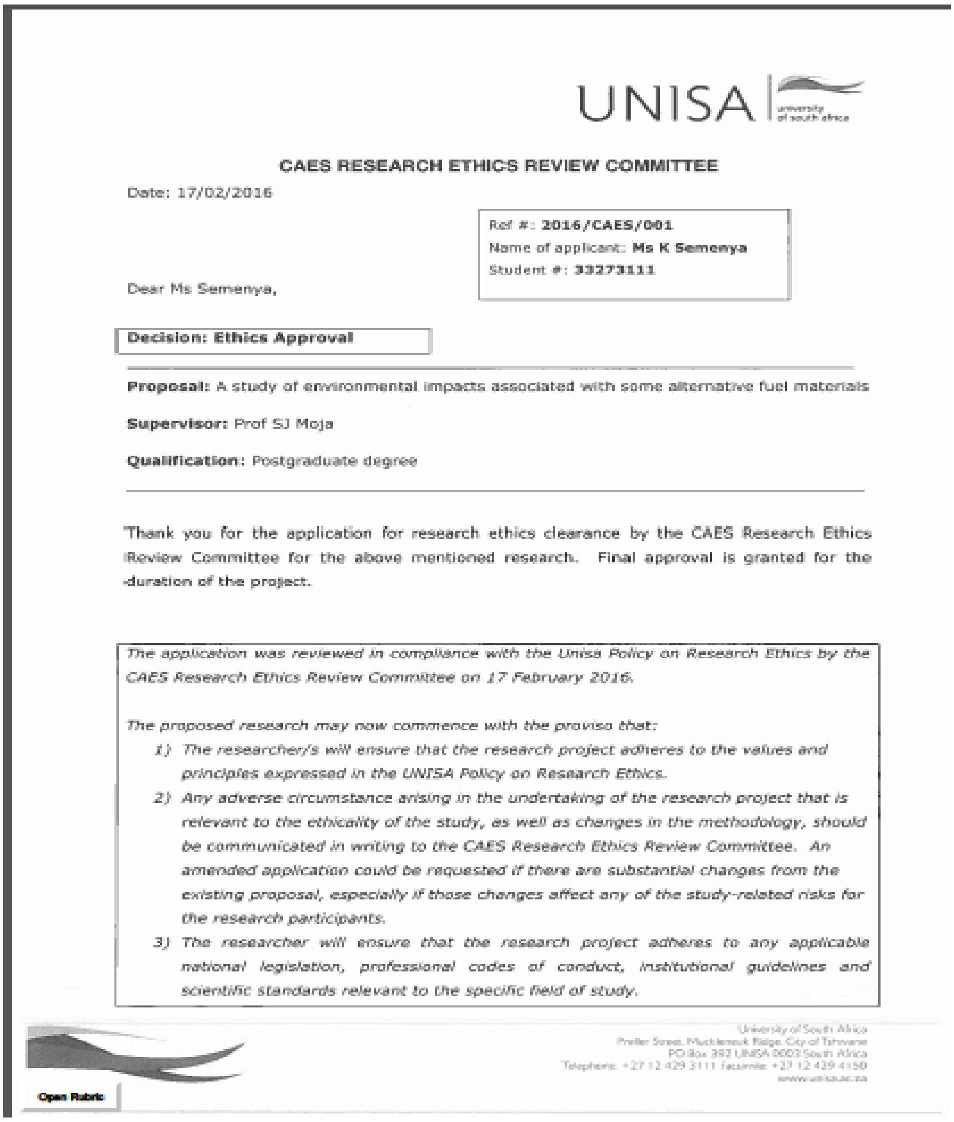
Participant Name & Surname………………………………………… (please print)

Participant Signature…………………………………………..Date…………………

Researcher's Name & Surname………………………………………(please print)

Researcher's signature…………………………………………..Date…………………

ANNEXURE 3: ETHICAL CLEARANCE



UNISA
university of south africa

CAES RESEARCH ETHICS REVIEW COMMITTEE

Date: 17/02/2016

Ref #: **2016/CAES/001**
Name of applicant: **Ms K Semenya**
Student #: **33273111**

Dear Ms Semenya,

Decision: Ethics Approval

Proposal: A study of environmental impacts associated with some alternative fuel materials

Supervisor: Prof SJ Moja

Qualification: Postgraduate degree

Thank you for the application for research ethics clearance by the CAES Research Ethics Review Committee for the above mentioned research. Final approval is granted for the duration of the project.

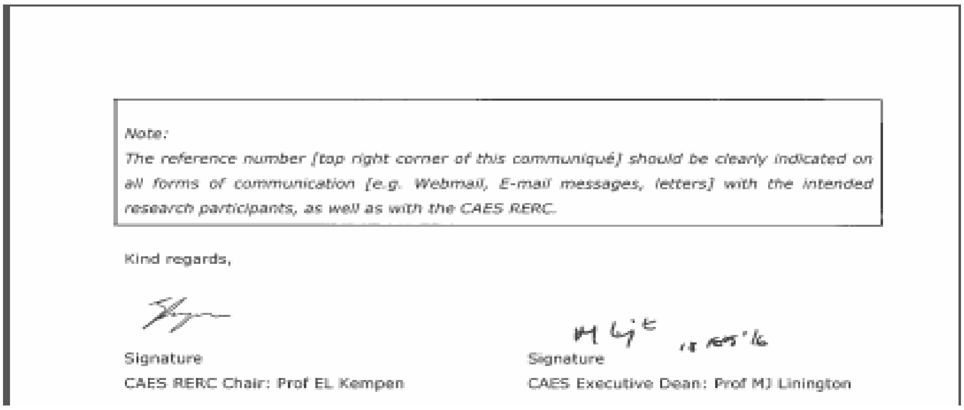
The application was reviewed in compliance with the Unisa Policy on Research Ethics by the CAES Research Ethics Review Committee on 17 February 2016.

The proposed research may now commence with the proviso that:

1) *The researcher/s will ensure that the research project adheres to the values and principles expressed in the UNISA Policy on Research Ethics.*
2) *Any adverse circumstance arising in the undertaking of the research project that is relevant to the ethicality of the study, as well as changes in the methodology, should be communicated in writing to the CAES Research Ethics Review Committee. An amended application could be requested if there are substantial changes from the existing proposal, especially if those changes affect any of the study-related risks for the research participants.*
3) *The researcher will ensure that the research project adheres to any applicable national legislation, professional codes of conduct, institutional guidelines and scientific standards relevant to the specific field of study.*

University of South Africa
Preller Street, Muckleneuk Ridge, City of Tshwane
PO Box 392 UNISA 0003 South Africa
Telephone: +27 12 429 3111 Facsimile: +27 12 429 4150
www.unisa.ac.za

Open Rubric



Note:
The reference number [top right corner of this communiqué] should be clearly indicated on all forms of communication [e.g. Webmail, E-mail messages, letters] with the intended research participants, as well as with the CAES RERC.

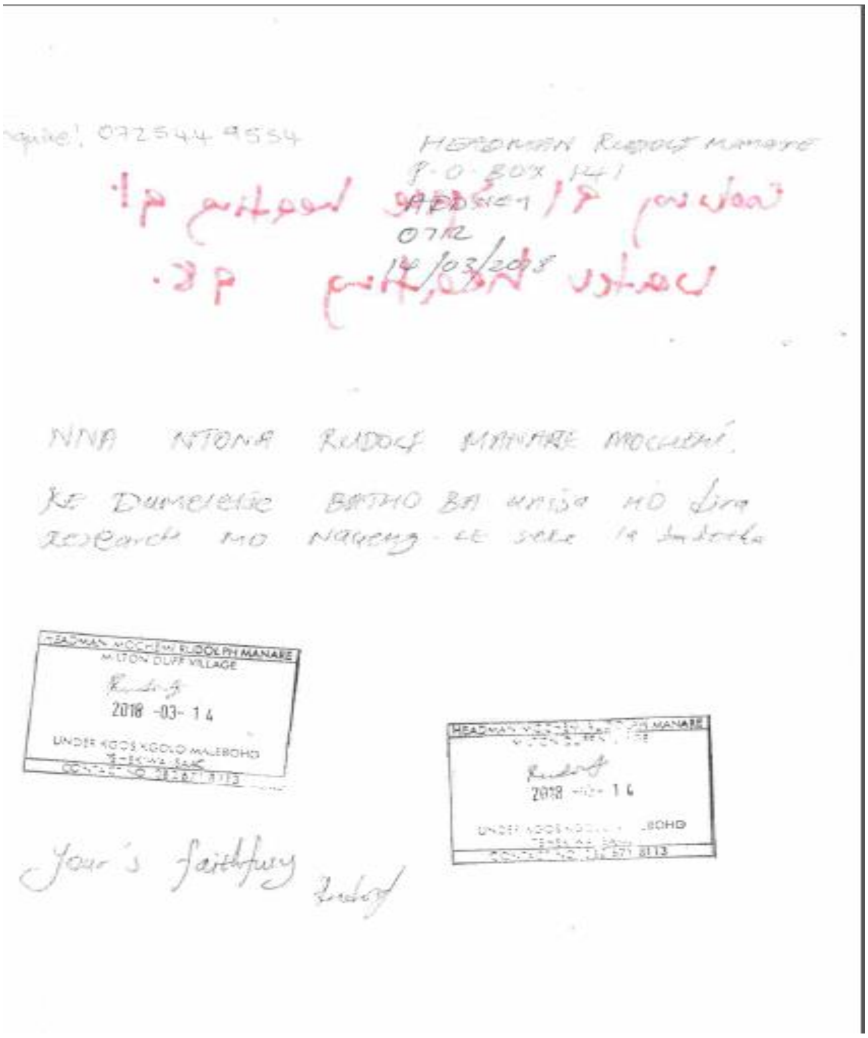
Kind regards,

18 FEB '16

Signature
CAES RERC Chair: Prof EL Kempen

Signature
CAES Executive Dean: Prof MJ Linington

ANNEXURE 4: TRIBAL AUTHORITY PERMISSION



quire!: 072544 9554

HEADMAN RUDOLF MANARE
P.O. BOX 141
[illegible]
0712
14/03/2018

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KE DUMELETSE BATHO BA [illegible] MO DIRA
RESEARCH MO NAGENG LE SEKE LA [illegible]

HEADMAN MOCHEMI RUDOLPH MANARE
MILTON DUFF VILLAGE
2018 -03- 14
UNDER KGOS KGOLO MALEBOHO
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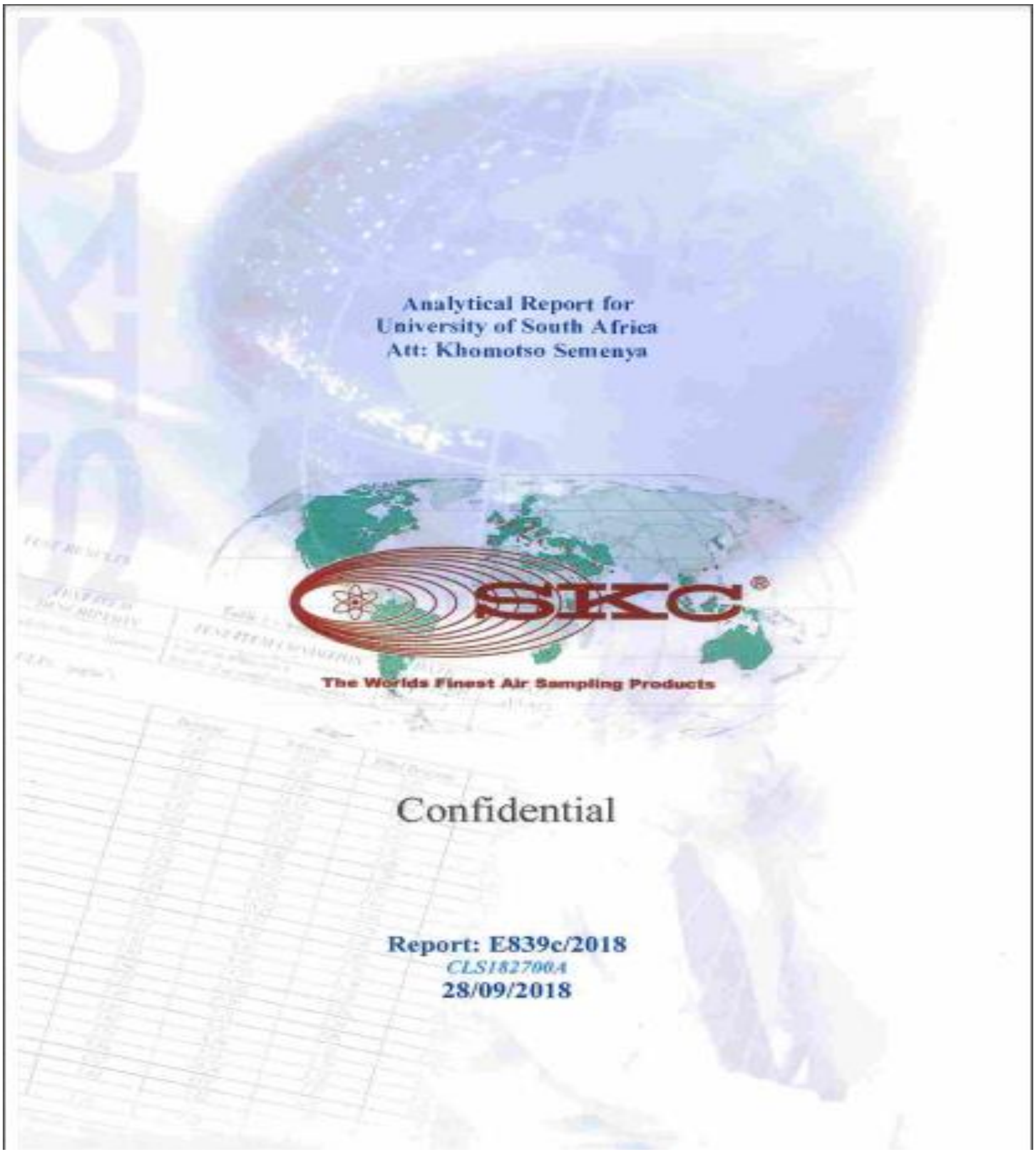
CONTACT NO [illegible] 8113

HEADMAN [illegible] MANARE
[illegible]
2018 [illegible] 14
UNDER KGOS [illegible] BOHO
[illegible]
CONTACT NO [illegible] 871 8113

Your's faithfuly

ANNEXURE 5: LABORATORY RESULTS



Analytical Report for
University of South Africa
Att: Khomotso Semenya

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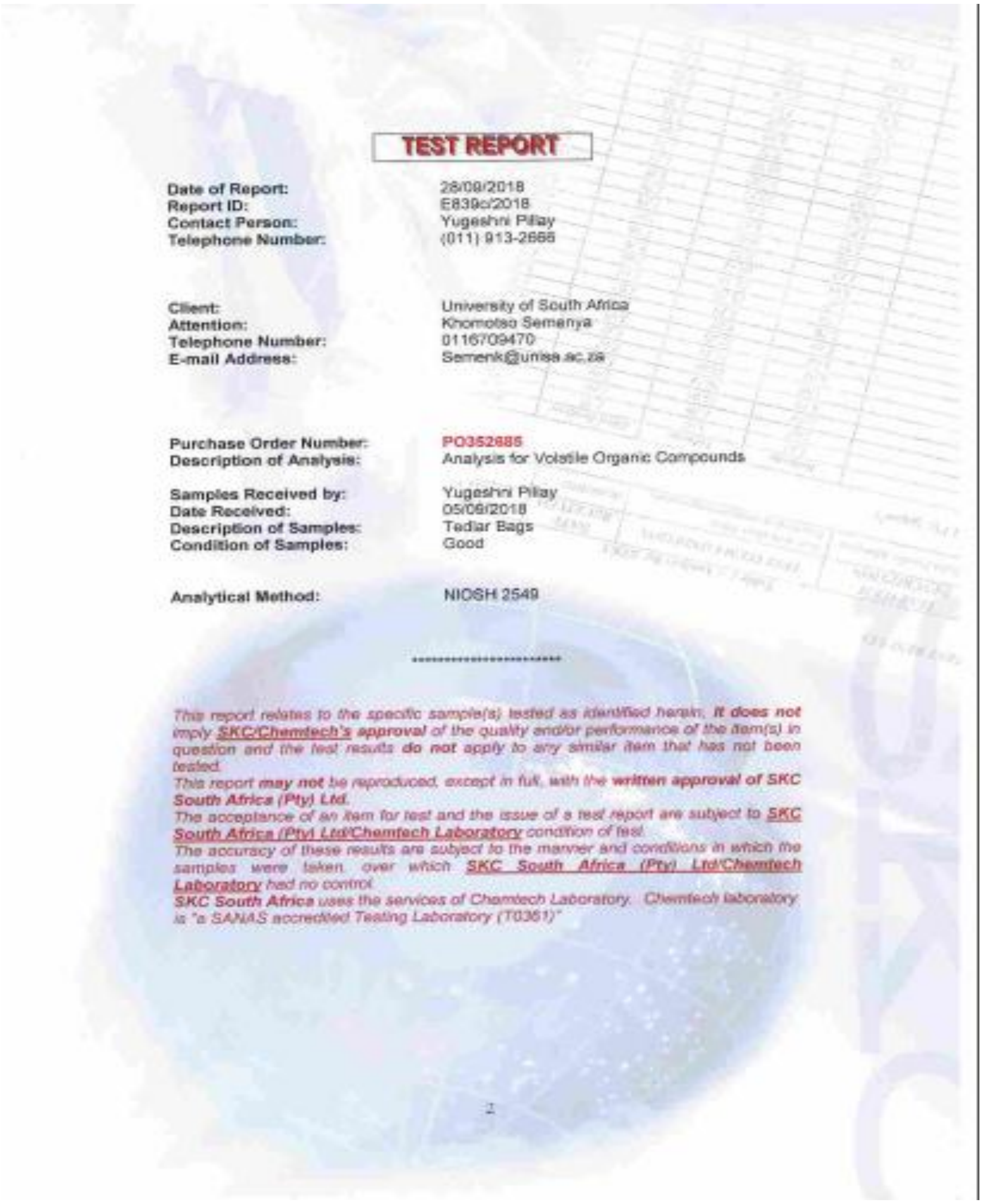
Report: E839c/2018
CLS182700A
28/09/2018



TEST REPORT

Date of Report: 28/08/2018
Report ID: E839c/2018
Contact Person: Yugeshni Pillay
Telephone Number: (011) 913-2666

Client: University of South Africa
Attention: Khomotso Semenya
Telephone Number: 0116709470
E-mail Address: Semenk@unisa.ac.za

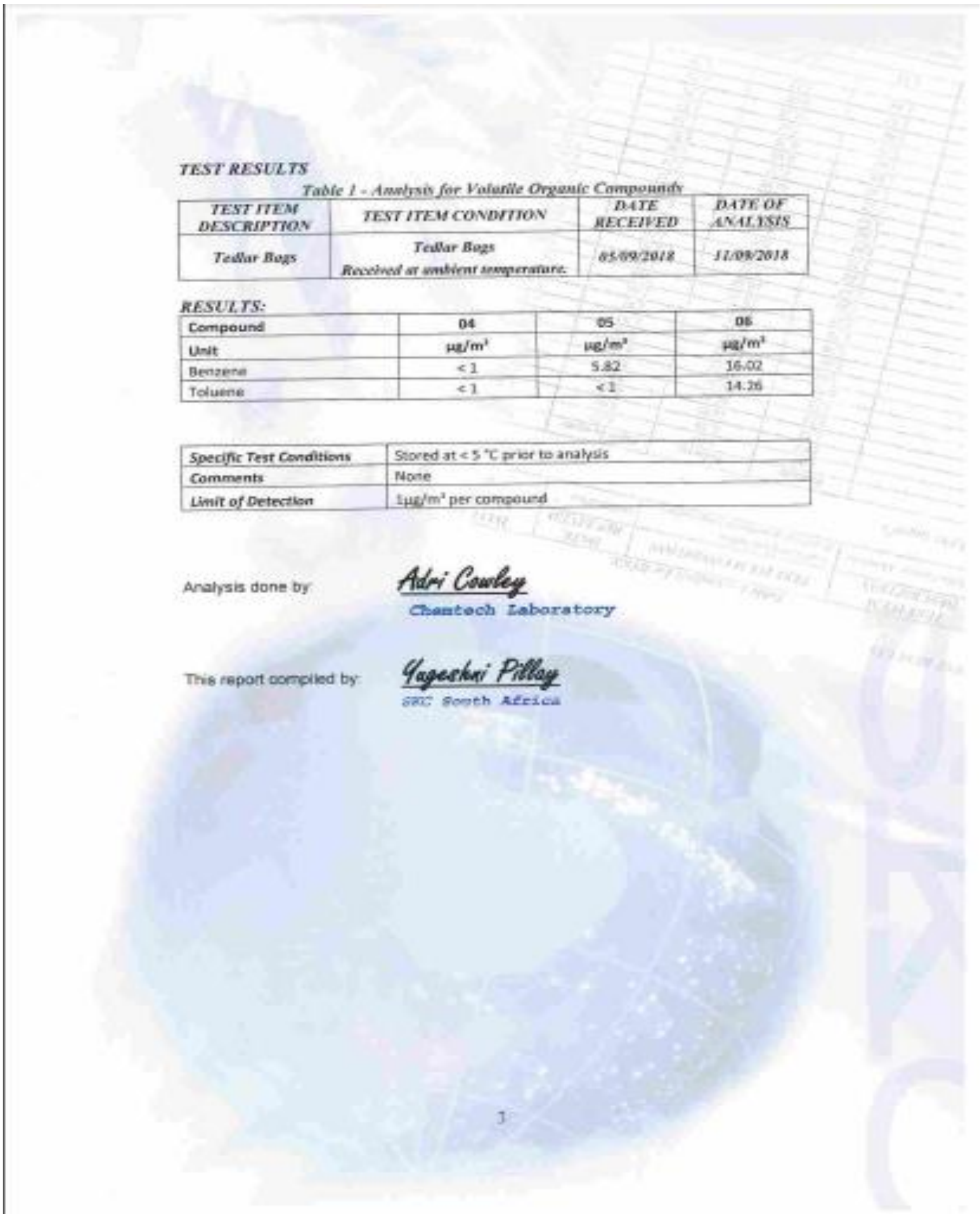
Purchase Order Number: PO352685
Description of Analysis: Analysis for Volatile Organic Compounds

Samples Received by: Yugeshni Pillay
Date Received: 05/08/2018
Description of Samples: Tedlar Bags
Condition of Samples: Good

Analytical Method: NIOSH 2549

****

This report relates to the specific sample(s) tested as identified herein. ***It does not imply SKC/Chemtech's approval*** *of the quality and/or performance of the item(s) in question and the test results* ***do not*** *apply to any similar item that has not been tested.*
This report ***may not*** *be reproduced, except in full, with the* ***written approval of SKC South Africa (Pty) Ltd.***
The acceptance of an item for test and the issue of a test report are subject to ***SKC South Africa (Pty) Ltd/Chemtech Laboratory*** *condition of test.*
The accuracy of these results are subject to the manner and conditions in which the samples were taken, over which ***SKC South Africa (Pty) Ltd/Chemtech Laboratory*** *had no control.*
SKC South Africa *uses the services of Chemtech Laboratory. Chemtech laboratory is "a SANAS accredited Testing Laboratory (T0361)"*



TEST RESULTS

Table 1 - Analysis for Volatile Organic Compounds

TEST ITEM DESCRIPTION	*TEST ITEM CONDITION*	*DATE RECEIVED*	*DATE OF ANALYSIS*
Tedlar Bags	*Tedlar Bags* *Received at ambient temperature.*	*05/09/2018*	*11/09/2018*

RESULTS:

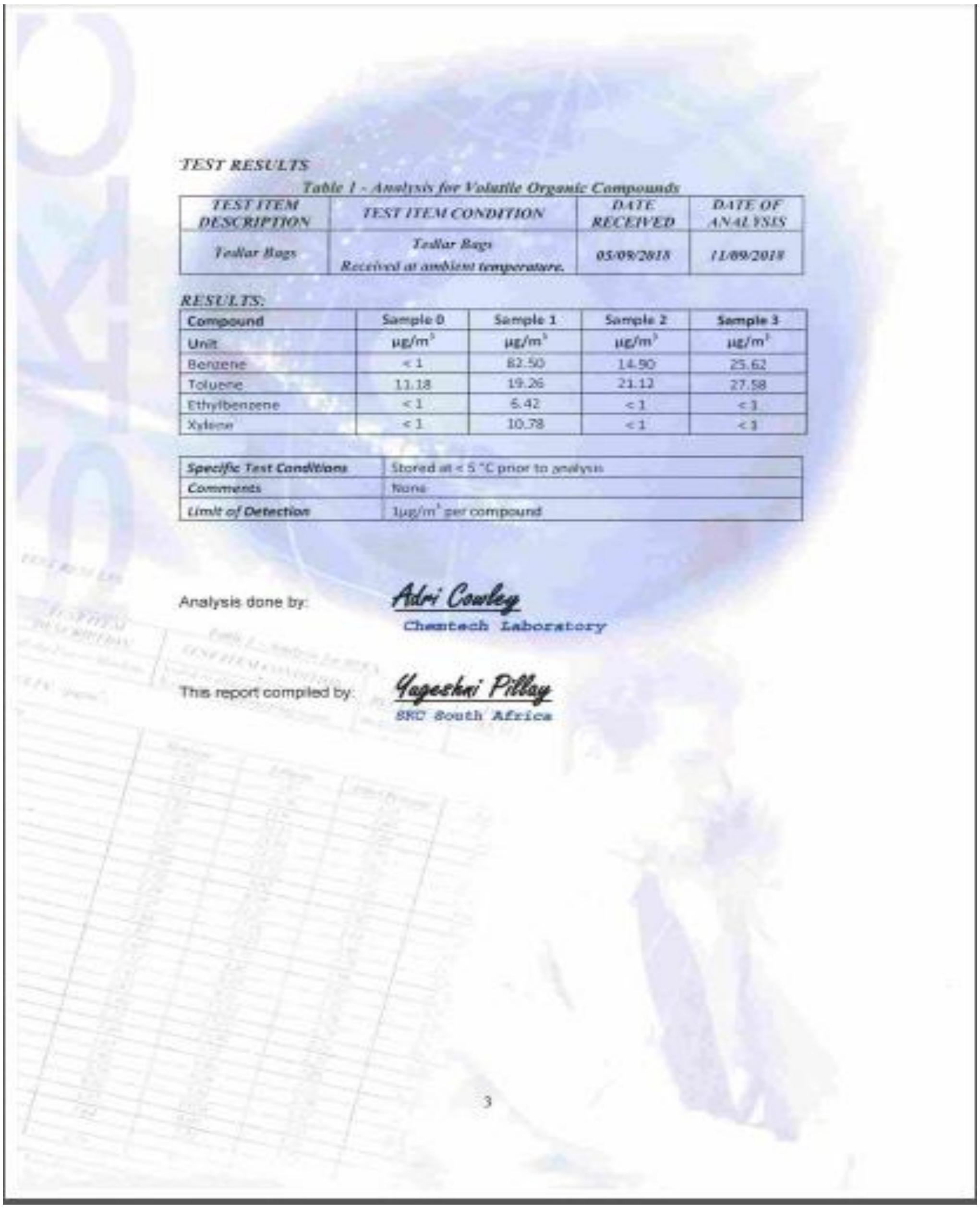
Compound	04	05	06
Unit	µg/m³	µg/m³	µg/m³
Benzene	< 1	5.82	16.02
Toluene	< 1	< 1	14.26

Specific Test Conditions	Stored at < 5 °C prior to analysis
Comments	None
Limit of Detection	1µg/m³ per compound

Analysis done by: Adri Cowley
Chemtech Laboratory

This report compiled by: Yugeshni Pillay
SGS South Africa

3



TEST RESULTS

Table 1 - Analysis for Volatile Organic Compounds

TEST ITEM DESCRIPTION	*TEST ITEM CONDITION*	*DATE RECEIVED*	*DATE OF ANALYSIS*
Tedlar Bags	*Tedlar Bags* *Received at ambient temperature.*	*05/09/2018*	*11/09/2018*

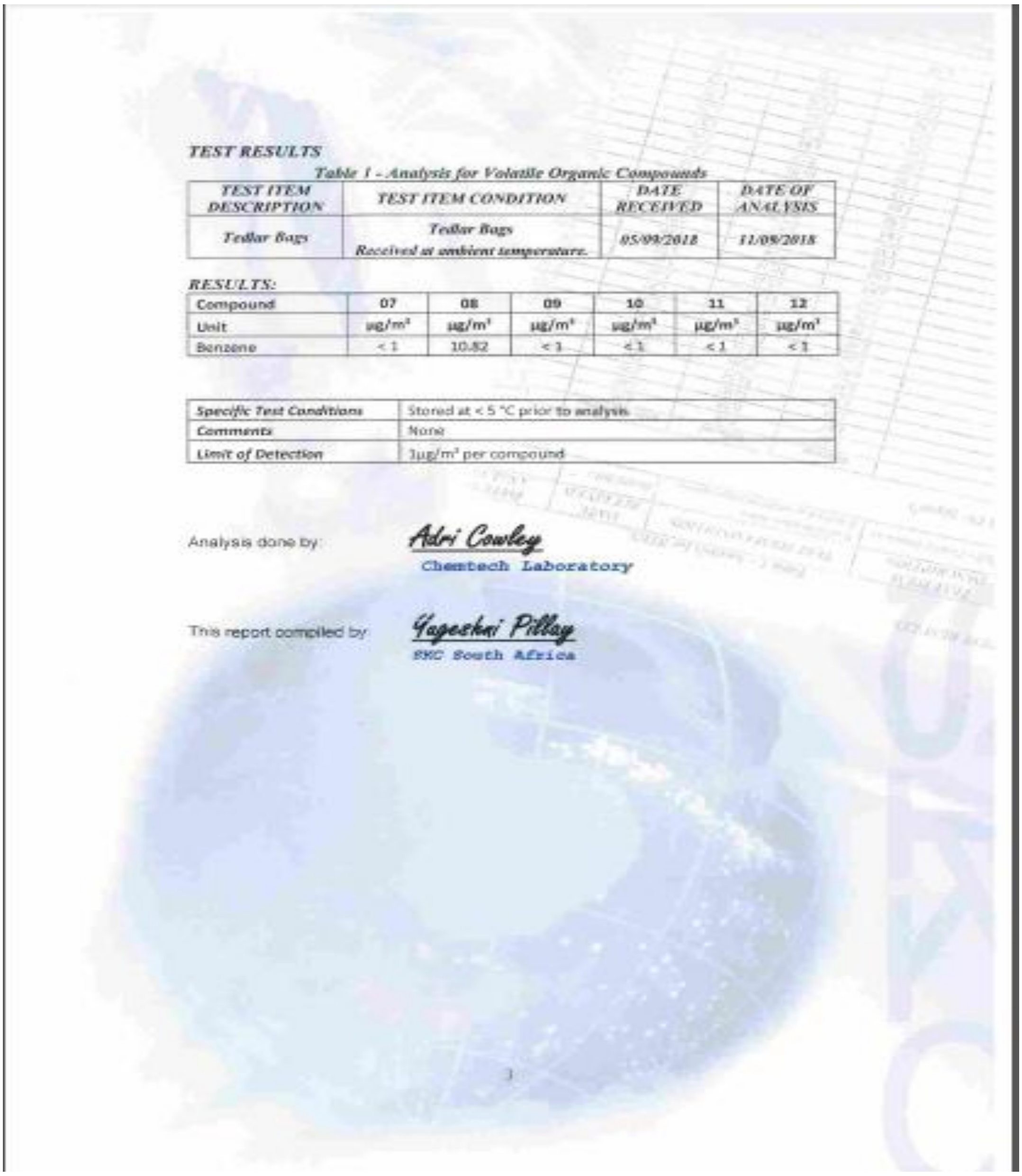
RESULTS:

Compound	Sample 0	Sample 1	Sample 2	Sample 3
Unit	µg/m³	µg/m³	µg/m³	µg/m³
Benzene	< 1	82.50	14.90	25.62
Toluene	11.18	19.26	21.12	27.58
Ethylbenzene	< 1	6.42	< 1	< 1
Xylene	< 1	10.78	< 1	< 1

Specific Test Conditions	Stored at < 5 °C prior to analysis
Comments	None
Limit of Detection	1µg/m³ per compound

Analysis done by: Adri Cowley
Chemtech Laboratory

This report compiled by: Yageshni Pillay
SRC South Africa



TEST RESULTS

Table 1 - Analysis for Volatile Organic Compounds

TEST ITEM DESCRIPTION	*TEST ITEM CONDITION*	*DATE RECEIVED*	*DATE OF ANALYSIS*
Tedlar Bags	*Tedlar Bags* *Received at ambient temperature.*	*05/09/2018*	*11/09/2018*

RESULTS:

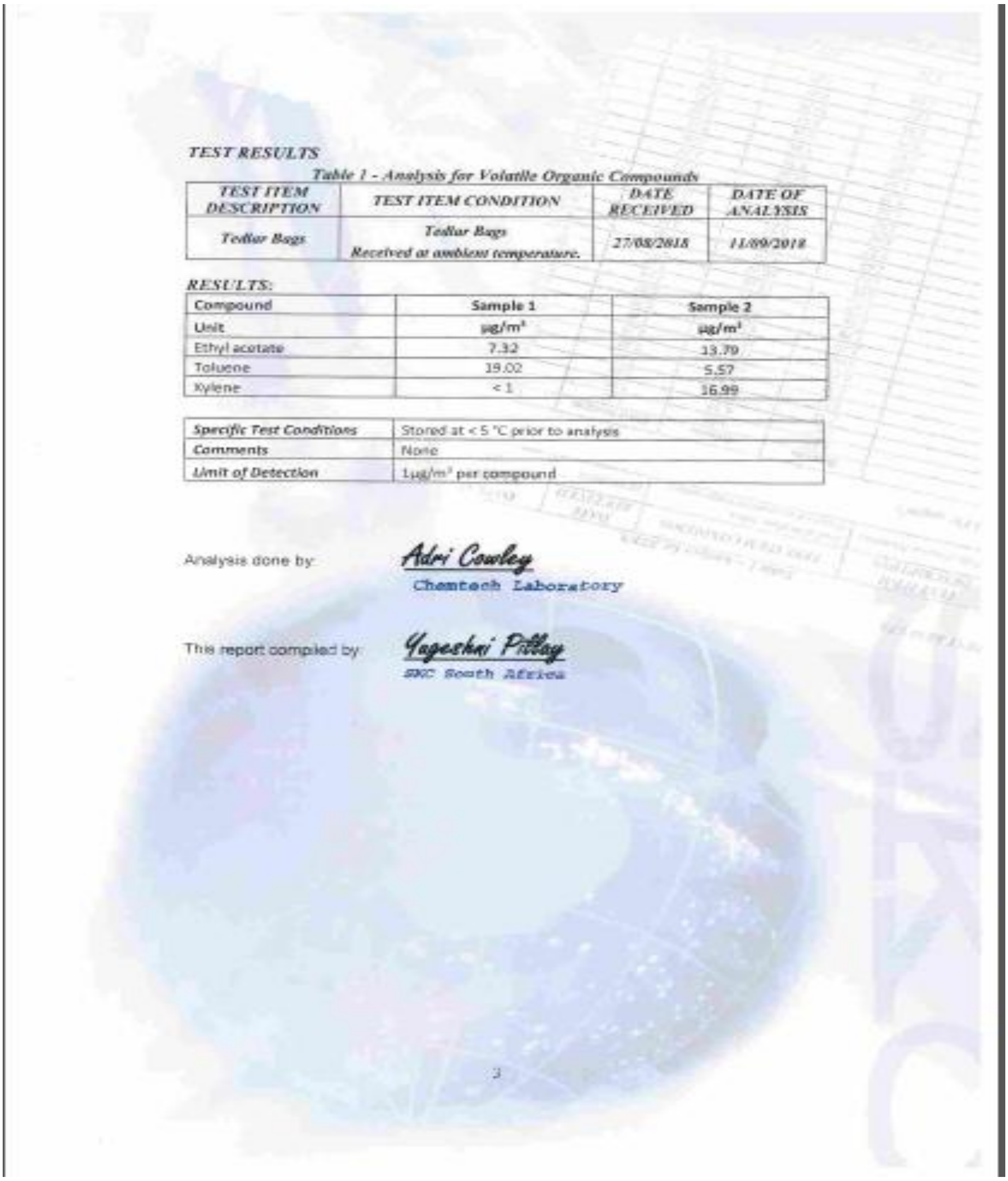
Compound	07	08	09	10	11	12
Unit	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³
Benzene	< 1	10.82	< 1	< 1	< 1	< 1

Specific Test Conditions	Stored at < 5 °C prior to analysis
Comments	None
Limit of Detection	1µg/m³ per compound

Analysis done by: Adri Cowley
Chemtech Laboratory

This report compiled by: Yageshni Pillay
SKC South Africa

3



TEST RESULTS

Table 1 - Analysis for Volatile Organic Compounds

TEST ITEM DESCRIPTION	*TEST ITEM CONDITION*	*DATE RECEIVED*	*DATE OF ANALYSIS*
Tedlar Bags	*Tedlar Bags* *Received at ambient temperature.*	*27/08/2018*	*11/09/2018*

RESULTS:

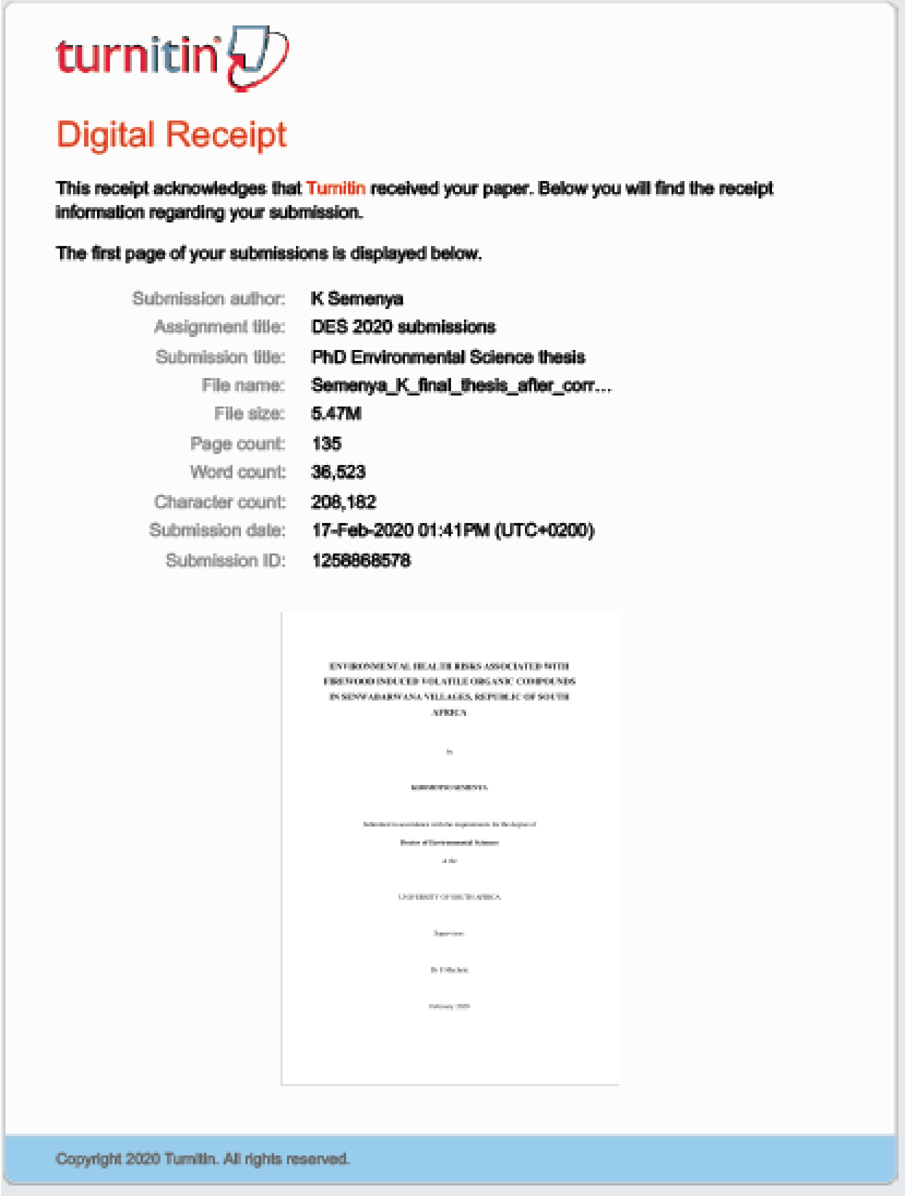
Compound	Sample 1	Sample 2
Unit	µg/m³	µg/m³
Ethyl acetate	7.32	13.79
Toluene	19.02	5.57
Xylene	< 1	16.99

Specific Test Conditions	Stored at < 5 °C prior to analysis
Comments	None
Limit of Detection	1µg/m³ per compound

Analysis done by: Adri Cowley
Chemtech Laboratory

This report compiled by: Yageshni Pillay
SKC South Africa

ANNEXURE 6: TURITIN DIGITAL REPORT



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Word count:	36,523
Character count:	208,182
Submission date:	17-Feb-2020 01:41PM (UTC+0200)
Submission ID:	1258868578

ENVIRONMENTAL HEALTH RISKS ASSOCIATED WITH FIREWOOD INDUCED VOLATILE ORGANIC COMPOUNDS IN SENWABARWANA VILLAGES, REPUBLIC OF SOUTH AFRICA