QUANTITATIVE ASSESSMENT OF TREE SPECIES AND WOOD VOLUME USED IN THE PRODUCTION OF FIRED CLAY BRICKS: THE CASE OF ZOMBA DISTRICT

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JOSHUA YAGONTHA MUNTHALI

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CHANCELLOR COLLEGE

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By

Joshua Yagontha Munthali

BSc (Geography & Earth Sciences)-Chancellor College

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UNIVERSITY OF MALAWI

CHANCELLOR COLLEGE

DECEMBER, 2020

DECLARATION

I declare that this thesis is a product of my own independent work, where other people's work has been used, acknowledgements have been duly made. This thesis has never been accepted in any degree program and is not being submitted concurrently in candidature of any degree.

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Full Legal Name

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Date

CERTIFICATE OF APPROVAL

We hereby declare that this thesis is the student's original work and where assistance has been sought this has been duly acknowledged. It is, therefore, submitted with our approval to the University of Malawi, as partial fulfillment of the requirement for the degree of Master of Science in Environmental Science.

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

Dr. M. Chikuni (Main Supervisor)

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

Mr. D. M. Mazibuko (Co-Supervisor)

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

Dr. E. Vunain PhD

Coordinator (Master of Environmental Science Program)

DEDICATION

Special dedication to my wife Salome Dossi Munthali, for always standing by my side when the going became tough and for always motivating me to work hard.

To my children Mwenecho, Wongani and Walusungu Munthali. The fact that you were always around me; gave me the needed motivation and strength to finish this work.

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ABSTRACT

Most of the buildings constructed in Malawi use burnt bricks. This study investigated tree species used for burning bricks in Zomba district because fired clay bricks depend on fuel wood which has exacerbated deforestation in the district. Parameters investigated included determination of plant species, Calorific Value (CV) of the same and volume of wood used in the process. Names of species were verified by taxonomists from NHBG, Calorimetry was used to determine CV, whilst Huber's formula was used to quantify volume of wood. Results indicate that 33 different tree species were used for burning bricks of which 25 were indigenous and 8 exotic. *Pterocarpus rotundifolius* (Sond) (Bleeedwood tree) had the highest CV of 53,705,934.735 J/Kg whilst *Newtonia buchananii* (Baker) (Forest newtonia) recorded the lowest CV of 43,576,691.89 J/Kg. Wood volume for both exotic and indigenous was more or less the same at 10.6 m^3 and 10.8 m^3 respectively though indigenous species outnumbered exotic species. There is a misconception that indigenous species have higher CV than exotics, however that is not the case from this study. It is thus imperative that communities are made aware of indigenous and exotic tree species with higher CV. Promoting propagation and sustainable use of such species will be a positive step in combating deforestation in the country.

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ABBREVIATIONS

CSEB	Compressed Stabilized Earth Brick
CV	Calorific Value
DEC	District Environmental Committee
EMA	Environmental Management Act
FRIM	Forestry Research Institute of Malawi
HB	Hollow Blocks
LGA	Local Government Act
NEP	National Environmental Policy
NHBG	National Herbarium and Botanic Gardens
NRMP	National Resources Management Policy
VNRMC	Village Natural Resources Management Committee

CHAPTER 1

INTRODUCTION

1.1 Background to the study

Since time immemorial, fired clay bricks have been the preferred building material of mankind. Fired bricks were in use in 4000 BC and were extensively used in the river valley civilisations of Egypt, Mesopotamia and Harappa (Maithel, 2008). With growing economies, population growth and rapid urbanization there is boom in construction activities in developing countries, and high demand for these fired clay bricks which are mostly dependent on fuel wood (Fuyane, *et al*., 2013; Bisht, *et al*., 2015).

In Malawi, for instance with high rates of urbanization, it is estimated that about 21,000 houses will be needed every year to meet the rising demand for housing in urban areas by 2020 (UN-HABITAT, 2010). With fired clay bricks being the main building materials this threatens the status of forests in Malawi. The use of fired clay bricks is problematic because most bricks used by urban developers in Malawi are done on a small scale without no any technological know-how and rarely seek sustainable fuel sources. These small-scale producers by comparison target naturally occurring vegetation and this disrupts flora and fauna patterns in the environment (Ahimbisibwe *et al*., 2016).

It should be appreciated that wood, is a renewable resource only when the rate at which it is depleted is less than the rate at which it is regenerated. This is certainly not the case in most developing countries where wood is a rapidly dwindling resource due to the multiplicity of its uses and the escalation in the magnitude of its consumption resulting from the burgeoning populations (Reddy, 1983). Comparatively, in developed countries, over the years brick kilns have basically evolved from rudimentary intermittent kilns to more complex energy-efficient continuous kilns (Maithel, 2008). In intermittent kilns, like the clamp kilns commonly used in Malawi, bricks and fuel are stacked in layers and the entire batch is fired at once; the fire is allowed to die out and the bricks allowed to cool after they have been fired. All these processes contribute to energy-inefficiency. With the realization that the fired clay bricks in Malawi are the dominant building material, an assessment of volume and the tree species used is of critical importance.

According to Brocard, *et al*., (1998**),** trees are very important in Africa since they not only preserve the environment by protecting the soil and retaining water by their root system, but they also provide the local population with food and domestic fuel. This is echoed by Tabuti, *et al*., (2003), who argues that in most African countries, indigenous woodlands provide both urban and rural populations with the greatest proportion of their fuel requirements. It is vital to be mindful and conscious that heavy and growing reliance on forest as a source of fuel in Malawi may prove to be unsustainable in the long run and the anticipated depletion of forests presents a real threat to economic welfare of the people. Sometimes in the quest for development, the potential of indigenous and exotic tree species to provide a sustained flow of diverse products in the long term and render services is ignored with disastrous consequences (Dhanya, *et al*., 2014).

There are a number of drivers of deforestation in Malawi, some of these include opening of forests for settlements and agriculture; tobacco growing, biomass energy, brick burning, and urbanization (Mauambeta, *et al*., 2010). All things being equal, in brick burning indigenous trees like *Brachystagia* species are more sought after, than exotic trees. This is so because of differential wood energy content. Indigenous trees have high calorific value (Zingano, 2005; Magembe, *et al.,* 2016). Important to note is that *Brachystagia* species are part of Miombo woodland (Abdallah & Sauer, 2007). *Miombo* is a vernacular word that has been adopted by ecologists to describe those woodland ecosystems dominated by trees in the genera *Brachystegia*, *Julbernardia* and *Isoberlinia* (Abdallah & Sauer, 2007; Kachamba, *et al*., 2016; Jew, *et al*., 2015).

Miombo woodlands make up a significant proportion of total forested land in Malawi and other countries. The Miombo ecoregion covers approximately 3.6 million km^2 in 10 countries of central and southern Africa and has been identified as one of five global wilderness areas that should be prioritised for conservation, due to its large area, high levels of endemicity, and importance as habitat for several threatened species and one such species is *Pterocarpus* angolensis (Jew, *et al*., 2015). Much as these Miombo woodlands are being threatened because of over exploitation, they are quite vital to rural and urban livelihoods. This was also observed by Syampungani, *et al*. (2009), who writes that 100 million people were directly or indirectly dependent upon Miombo woodland for their daily needs. Miombo woodlands affect the livelihoods of local communities through the provision of products such as medicines, energy, food, fibers, and construction and craft materials. The rural communities, for instance, consume a variety of edible fruits, which are normally gathered and eaten within the locality, while some are sold in the local markets.

There is rising concern on resource scarcity voiced by both the Malawian government and the building material industry. As wood is the prime source of energy both for domestic and for brick firing, there is immense pressure of deforestation on the fast declining forests (Zingano, 2005). According to (Yaron, *et al.*, 2011), firewood provides 95% of rural household energy. Much as there are differences in statistics regarding the energy contribution of fuelwood to the country; but statistics shows its contribution is immerse. With this huge demand on fuelwood, it is not surprising as such that between 1990 and 2010, forest cover in Malawi has declined from 41% to 34% (FAO, 2010). The (GoM, 2010), consider deforestation and associated soil degradation as major environmental problems in Malawi.

According to GoM (2010), forest resources in customary land are nearing to extinction, with only 7% wooded areas remaining. This is a worrisome development in the sense that Malawi's economic development and the livelihoods of her population are largely dependent on natural resources. In order for the country to experience sustainable economic growth and alleviate poverty, Malawi must conserve its valuable environmental resources

(GoM, 2010). This is echoed by Yaron, *et al*., (2011), who noted that forestry resources are critical in supporting livelihoods in Malawi and therefore the resources should be conserved.

Worldwide interest has been focused on the development of technologies using new and renewable sources of energy like biomass and others. The world's biomass production is approximately 985 million tons per year (Gokcol, *et al*., 2009). It is vital to appreciate that biomass can be examined in three categories such as woody, non-woody, and animal wastes. Many studies have demonstrated that just minor technology improvements could increase the efficiency of biomass energy production and use significantly, maintain high productivity of biomass plantations on a sustainable basis and mitigate environmental and health problems associated with biomass production and use (Gokcol, *et al*., 2009). For instance through process of anaerobic digestion of wet biomass like manure and vegetable waste, biogas can be produced which can be used for heating. Other processes like gasification or fermentation of woody biomass can lead to gas fuels and liquid fuels respectively, all vital for community use. Malawi as a country, such understanding of diverse use of biomass is critical at different levels. For example communities can be empowered how wet biomass can be used to produce heat through biogas. This can reduce overreliance over trees.

Economically, unsustainable use of natural resources adversely impacts on the rate of economic growth in Malawi. The main contributors to the annual revenue loss due to resource degradation are forestry degradation (47.8%) and soil degradation (33.8%) (GoM, 2010). Also, forests are an important source of various non-wood products such as mushrooms, bush meat, fruits, juices, honey, and medicines), most of these are produced and used in the informal sector (Yaron, *et al*., 2011). Deforestation has also affected water catchment areas and destroyed watersheds, affecting the quantity and quality of the water supplies they contain. In some cases, deforestation has resulted in unprecedented floods and loss of life. Scarcity of fuel wood caused by deforestation has also been a major problem to the majority of people, who are and therefore poor as they are cannot afford to use alternative sources of fuel. Forestry resources are crucial in supporting livelihoods, infrastructure development and energy in Malawi. Apart from providing a diverse range of wood and non-wood products, the sub-sector is important for soil and water conservation for agriculture and household use, provision of animal habitat, beautification of the countryside, enhancement of ecotourism and biodiversity, and regulation of climate change (GoM, 2010).

As such it is really important that the use of burnt bricks should be comprehensively analysed for proper alternatives to clamp kilns to be sought so as to minimize unsustainable use of forests, in the country.

1.2 Problem Statement

Biomass is Malawi’s main source of energy, mainly in the form of wood. It accounts for an estimated 88.5% of total demand, ranging from 98% in the household sector through 54% in the industrial sector and 27% in the service sector to 5% in the transport sector. In terms of wood equivalent, the total demand for biomass energy in 2008 was estimated at 8.92 million t, about 13.5 million m^3 (Mauambeta, *et al*., 2010).

High demand of wood as forests product should be a source of concern. Forests are important as they have multiple functions. Some of them include source of livelihood, like fruits which some people sell in the process enhancing economic well-being.

With rapid urbanization in Malawi, fired clay bricks have become an important enterprise. According to Mauambeta, *et al*., (2010), a lot of wood is needed for brick burning. He further argues, deforestation is acute around major cities, and towns in Malawi because of the need to supply burnt bricks to cities. In Lilongwe, for example, the demand for wood for burning bricks has exerted pressure on mango trees in communal areas and indigenous trees in graveyards (Mauambeta, *et al.*, 2010).

It is this unsegregated use of tree species which should be a source of concern-as even trees critical to peoples livelihood are being harvested for burning bricks (Mauambeta, *et al*., 2010). The clay brick firing process may be classified based on the structure of the firing system adopted either intermittent or continuous. Intermittent kilns include clamp kilns, scotch kilns, round kilns, annular kilns, zigzag kilns (Akinshipe & Kornelius, 2017). Malawi as a country the predominantly used kiln when firing clay bricks are the clamp kilns. They are referred as such because they are so energy inefficient. In other countries, especially developed countries brick firing has evolved beyond ancient, traditional, basic and common techniques, to more sophisticated, energy efficient technologies like the use of continuous kilns where bricks pass through a stationery firing zone like tunnel kilns (Kinship & Kornelius, 2017).

According to Sola, *et al*., (2017) in Sub-Saharan Africa, wide dependence on wood fuel harvested from forests and woodlands could significantly deplete these natural resources. As Zingano, (2005), argues, the construction industry in Malawi mostly uses burnt bricks that are prepared in scove kilns because concrete blocks are more expensive than these bricks. As a remedy, there were a number of fast growing exotic woods that were being planted by government and were recommended for firewood such as Blue gums (*Euclayptus camadunsis/glandis/ terecornis)*, *Gmelina* (*Gmelina arborea)* and *Pine* (*Pinus patula*) but People's own intuition led them to believe that there was more energy in indigenous hardwoods than there was in all these exotics (Zingano, 2005). To make matters worse, the natural hardwoods are available in the countryside at almost no cost. This was the mistake that was made and continues to be made that has contributed to the deforestation in this country (Zingano, 2005). The new 2030 Agenda for sustainable development is cognisant of global issues like land degradation, unsustainable consumption and production patterns which urgently require a shift in our lifestyles and a transformation of the way we think if a reverse of degradation of forest and land is to occur. Surprisingly, Malawi continues relying on fired clay bricks which consume huge volume of fuel wood in most building projects despite the pressure it adds to already depleted forests.

It was on this basis that this study was done to quantify the volume of wood used per kiln, determine calorific value of tree species and identify the tree species used in order to give an indicator of the threats facing forests generally and specified tree species in particular.

1.3 Objective of the study

The main objective of the study was to quantify the wood volume used in burning bricks, determine calorific value and identify the tree species used at specific brick-kilns in Zomba district.

The specific objectives of the study were to:

i. Quantify the wood volume used in the production of fired clay bricks in Zomba
ii. Assess the diversity of the tree species used in firing clay bricks in the area
iii. Determine the relationship between the soil volume burnt and the amount of wood volume used in the area
iv. Determine the calorific value of tree species in the study area

1.4 Justification and significance of the study

Brick burning is one important parameter that contributes to deforestation in Malawi. However, there is paucity of information regarding species used in brick burning, their associated calorific value and the volume of wood required to burn the bricks. Knowledge of wood volume of individual tree species is critical as it gives an indicator of usage of these species. Also determining calorific value of tree species is vital, as communities will be made aware of this differential aspect so that all factors being equal trees with higher calorific value can be targeted to reduce wood volume usage. Also, some tree species have great economic and ecological value, and need protection. This study will give an indicator of the usage of such trees, in terms of volume in the study area. This will help inform policy regarding usage of such tree species and foster other forest management strategies and solutions which will be of benefit to people in the area and nation at large.

1.5 Limitations of the study

1. Limited resources required for the administration of the study which had a bearing regarding coverage of the area of study.

2. In some cases uncompromising owners of brick-kilns; refusing to accept wood and their brick-kiln to be measured due to superstitious beliefs which had a bearing regarding brick kilns visited

3. Generalization of estimation of deforestation using a generic formula applicable to miombo woodlands

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter provides a synopsis of the studies done elsewhere and in Malawi focusing on the various issues addressed in the study linked to conceptual and theoretical framework.

2.2 The concept of Clamp Kilns and Tragedy of the Commons as Conceptual and Theoretical framework.

Clamp kilns are a common site in Malawi as a means of producing fired clay bricks. Clamp kilns are where bricks are fired in batches; fire is allowed to die out and the bricks are allowed to cool after they have been fired. The heat trapped in the bricks and the kiln is lost during cooling, making this a fuel-inefficient technology (Basu, *et al*., 2016). This approach of brick making continues contributing to deforestation in Malawi. Another important factor to appreciate is that brick burning using these clamp kilns is a free and small enterprise. As such it is not regulated, done haphazardly, where brick burners choose where to construct such clamp kilns. Forests are an important resource bearing in mind their multiple functions to mankind.

According to Otum, *et al*., (2017), the "tragedy of the commons" occurs when individuals act independently and rationally according to their own self-interest, and as a result, act against the interests of the whole community by depleting a common resource. Further, Otum, *et al*., (2017), argues that "tragedy of the commons" in society mostly has to do with the environment such as forests, river and oceans. The use of Clamp kilns, is one of a typical example of the "tragedy of the commons as it contributes to deforestation with negative connotation to the environment. Forests help in controlling soil erosion as they reduce run-off, which help lessening siltation of rivers. Forests are an important resource in the face of global warming as they are key in sequestrating greenhouse gases helping mitigate global warming. They are also key as an important socio-economic resource where they are source of livelihood to most people in form of fruits and help maintain soil fertility where top soil removal is minimized. Clamp Kilns are also threatening the livelihood of many people as they are situated in mostly fertile areas.

Schematic representation of brick burning in Clamp Kilns

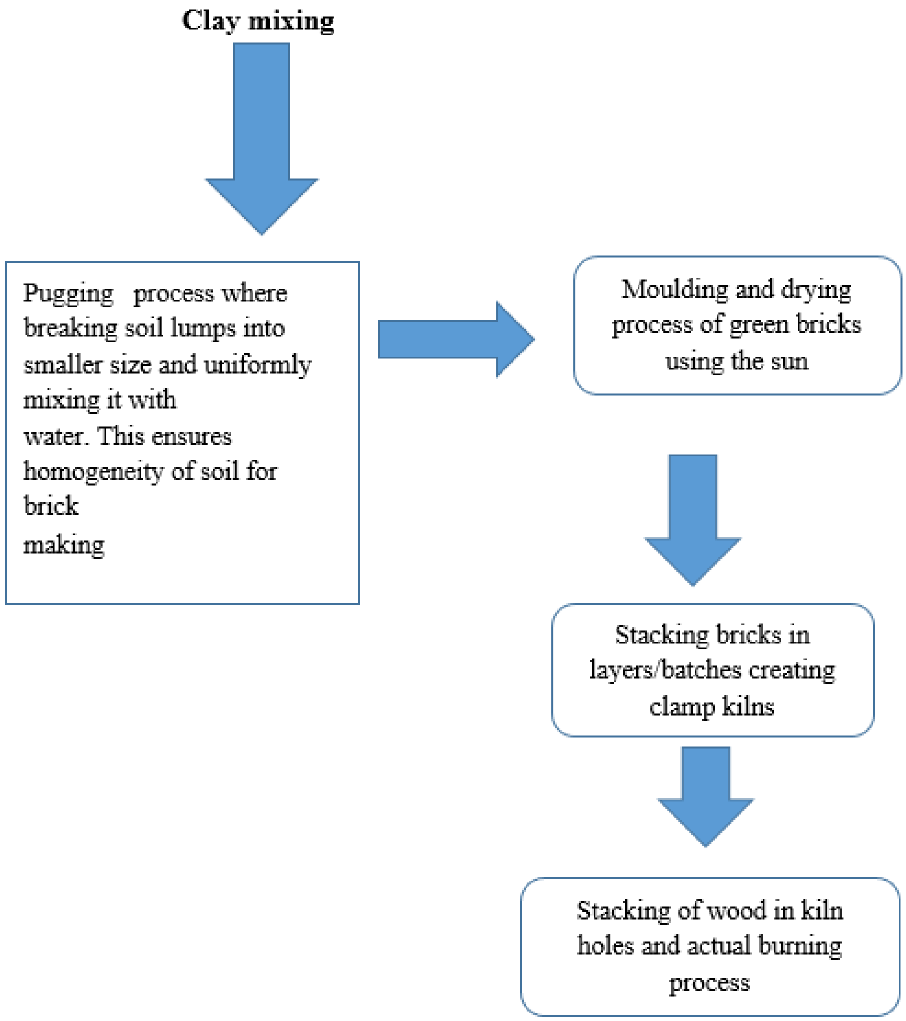

Figure 2. 1: Schematic representation of brick burning in Clamp Kilns

2.3 Quantification of Fuel wood and tree species used during brick burning

Most developing countries use fuel wood as a source of energy during brick burning with disastrous consequences on the environment. According to Alam (2006), in Sudan who mainly did his study around Khartoum, Kassala and Gezira, observed that total potential deforested wood was 10,624 m^3, in which the total deforested round wood was 3,664 m^3 and deforested branches was 6,961 m^3. Regarding tree species Alam, (2006), reports 13 tree species were used as fuelwood: Sunt (*Acacia nilotica*), Talh (*Acacia seyal*), Kitir (*Acacia mellifera*), Seyal (*Acacaia tortilis*), Laot (*Acacia nubica*), Haraz (*Faidherbia albida*), Neem (*Azadirachta indica*), Eucalyptus (*Eucalyptus* spp.), Mesquite (*Prosopis juliflora*), Tundub (*Capparis decidua*), Mango (*Mangfiera indica*), Grape fruit (*Citrus paradisi*) and Guava (*Psidium guajava*).

The study referred above has quantified generically regarding the volume of usage of fuel wood. However it fails to give a picture of individual tree species usage which is critical regarding indicative element of species use. However it will be of use to this study as it will be used as a comparative analysis regarding species use, if they will be similarities in some species use. It will help give an indicative commonality in species use.

In Tanzania, specifically Morogoro, Magembe and Makonda (2016) carried out a study to determine the volume contribution of preferred tree species in burning bricks, where they documented that *Burkea africana* (4,078 m3), *Azadirachta indica* (1,212 m^3) and *Mangifera indica* (872 m^3) together made up 8,027 m^3 of the total tree species volume consumed as fuelwood in brick making. The rest of the species (*Eucalyptus spp*, *Senna siamea*, *Pithecellobium dulce* and *Delonix regia*) contributed 585 m^3 of the total volume. Magembe and Makonda (2016), further argues that high volume contribution for the named species (*Burkea africana*, *Azadirachta indica*, *Combretum molle*, *Senna spectabilis* and *Mangifera indica*) suggests that they are mostly used as fuel wood in brick making. On the other hand, low volume contribution for the other tree species means that such species are not frequently used as fuel wood in brick making, to which they attribute to relative unavailability of some of the tree species as the case for *Senna spectabilis*. The above discussed information is summarised in the Table 2.1.

Table 2. 1: Tree species and volume used when burning bricks. Source; Adapted from Magembe and Makonda, 2016

Vernacular name/common name	**Scientific name/botanical name**	**Volume(m^3)**	**Percentage volume wise**
Mkarati	*Burkea africana Hook*	4,078	47.4
Muarobaini	*Azadirachta indica A. Juss*	1,212	14.1
Mlama	*Combretum molle R.Br. Ex G. Don*	933	10.8
Mbiriti	*Senna siamea (Lam.) Irwin & Barneby*	932	10.8
Mwembe	*Mangifera indica L.*	872	10.1
Mjohoro	*Senna spectabilis (DC.) H.S. Irwin & Barneby*	373	4.3
Mkaratusi	*Eucalyptus spp*	119	1.4
Mchongoma	*Pithecellobium dulce (Roxb) Benth*	70	0.8
Mkrisimasi	*Delonix regia (Bojer ex Hook.) Raf.*	23	0.3
Total		**8,612**	**100**

The study done by Magembe and Makonda (2016), gives an important case regarding quantification of tree species in terms volume usage in brick burning. The study will be used as a comparative analysis regarding usage of tree species in the study area in Zomba. This will give an indicator whether regionally there are some similarities regarding tree species usage in terms of volume. However the study fails to give how many kilns were visited and how much soil volume was burnt using such tree species. Such information is key if correlation analysis can be done.

In Malawi the assessment for resources in 2003 listed the country's energy sources as the following Biomass 93%, liquid funds 3.5% Electricity 2.3% coal 1% and Renewable 0.2% (Zingano, 2005).The forest cover for Malawi was 34% in 1984 but this has been reduced to 26% in 2004. The demand for burnt bricks in the construction industry has stimulated a huge demand for hardwood for burning the bricks. With the notion that indigenous species have high calorific value, the demand is high on indigenous species. To ascertain this notion, Zingano (2005), analysed energy content of some tree species as shown in the Table 2.2.

Table 2.2: Energy content of some tree species Source: Adapted from Zingano, (2005)

Common Name	**Biological Name**	**Energy Content MJ/ kg**	**Growth rate m^3/ ha**
Blue gum	*Eucalyptus camadulensis*	19	187.2
Gmelina	*Gmelina arborea*	18	73.5
Pine	*Pinus patula*	17.8	10-30.
Indegenous hard woods	*Brachystagia species*	21.5	3.51
Mean Calorific Values(CV)		19.2	

Important to note is that *Brachystagia* species are part of Miombo woodland (Abdallah & Sauer, 2007). Miombo woodlands make up a significant proportion of total forested land in Malawi and other countries. The Miombo Eco-region covers approximately 3.6 million km^2 in 10 countries of central and southern Africa and has been identified as one of five global wilderness areas that should be prioritized for conservation, due to its large area, high levels of endemicity, and importance as habitat for several threatened species (Jew, *et al.*, 2015).

Malawi unfortunately continues to be leading in terms of fuel wood consumption compared to some neighboring countries as shown on Table 2.3. This need concerted efforts and solutions to sources which contribute to high traditional fuel wood use. Table 2.3 Energy consumption for Malawi and some Neighboring Countries.

Table 2. 3: Wood fuel consumption in different countries Source: Adapted from Zingano, (2005)

Country	**Traditional Fuel Consumption (% Of Total Energy Requirement)**
Kenya	64.9
Mozambique	80.3
Tanzania	82.6
Zambia	87.3
Zimbabwe	66.2
Malawi	85

The major building materials in Malawi continues to be fired clay bricks. With huge demand on fuel wood this should be a source of concern, as exemplified of Figure 2.2 showing dominance of bricks as building materials.

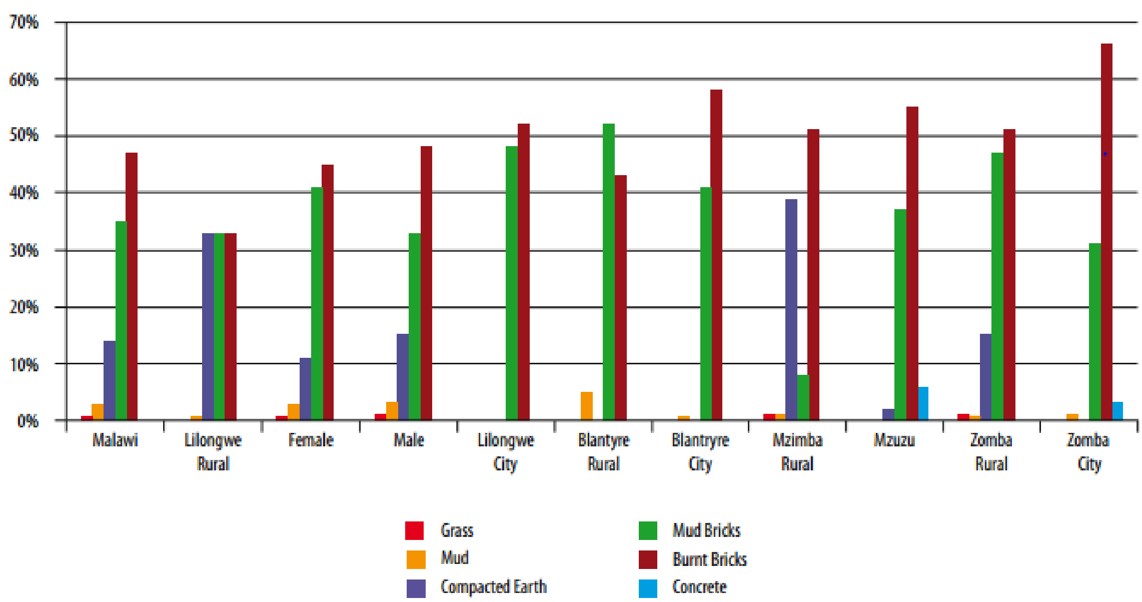

Figure 2.2: Building materials in Malawi. Source: Government of Malawi 2010

The huge demand of fuel wood in burning bricks is enhanced in some cases by limited use of alternatives by most brick makers. As Magembe, *et al*., (2015), argues that majority of brick makers 97.9% in Morogoro Tanzania have shown to benefit from fuelwood and few of them managed to use other energy. Only one alternative energy source used by brick makers was rice husks, which accounts 2.1% of the total energy consumption on brick making in Morogoro Municipality.

The same is echoed by Ahimbisibwe, *et al*., (2016), who argues that rural artisans rarely seek sustainable fuel sources like coffee husks or sawdust that have been adapted to fuel larger commercial kilns. Small-scale producers by comparison target naturally occurring indigenous species.

Much as admixtures like organic matter, which include rice husks, sawdust and others are not mostly used by many small scare brick burning producers, they play a crucial role in the brick burning process. According to Okunude, (2008), these admixtures help a brick to be uniformly burnt as pores produced as admixtures burn permit the heat to reach into the inner most part of the core, thereby avoiding unburnt cores. They also serve as extra fuel which provide more heat for the firing. As such the usage of these admixtures should be encouraged in Malawi.

2.3 Brick making and land degradation

Land is an important natural resource which is present on Earth in limited amount. The degradation of this natural resource is one of the most serious problems facing the world today (Das, 2015). One of the major contributors to land degradation is brick making. According to Das (2015), brick making consumes large amounts of clay which leads to top soil removal and land degradation. Large areas of lands are destroyed every year especially in developing countries due to collection of soil from a depth of about 1 to 2 m from agricultural land. These affected areas are expanding rapidly due to increase in brick production.

Brick making as an enterprise is also most of the time situated in productive and potential agricultural lands. In most cases, brick fields are mostly situated on river line fertile agricultural land. For example Abdallah, (2015), noted that brick making is practiced on the Blue and River Niles banks, the most fertile lands where it competes with urban agricultural activities that are traditionally practiced. The same is observed in Morogoro Municipality in Tanzania where brick making is mainly practiced on the river banks where it competes with urban agricultural activities (Magembe, *et al*., 2016).

The same happens in Nepal where brick kilns are mainly concentrated around Kathmandu valley and in Terai regions where there are more than 500 brick kilns established. These brick kilns remove top soil for brick making and this has direct impact on agricultural crop production as it reduces fertility status of the soil. The negative impact of topsoil removal results in reduction in agricultural output (Busht, 2015). The same problem is encountered in India where brick kilns are also unfortunately largely situated on fertile agricultural land, as there brick manufacturers encounter good drainage conditions and the required silty clay loam soils (Ortlepp, 2015).

In Sudan, practicing of brick making on the river Nile banks in the midst of agricultural lands has multiple effects on vegetable and fruit tree production (Alam, 2006). Due to the heat, soot, and smoke particles deposited on the leaves, plant respiration and photosynthesis are affected. Malawi as a country is not spared from brick making which affect agricultural land. According to GoM, (2010), mining for construction materials such as sand and use of clay for bricks has severe negative impacts affecting land systems and agricultural productivity, with the collapse of which affects sedimentation, hydrology and river function.

According to UN-Habitat, (2012), everyone has a relationship to land. In rural areas, land is essential for livelihoods, subsistence and food security. It is important to appreciate that Malawi's economy remains agro-based with the agriculture sector accounting for over 40%

of GDP, employs about 85% of the labour force and accounts for 75% per cent of foreign exchange earnings (GoM, 2010).

2.4 Brick making and natural resources depletion

Different countries are also experiencing the impact of brick making on their natural resources. For example, the total annual consumption of wood by the brick making industries of the northern States of Sudan was found to be about 549,000 m^3 equivalent to 183,000 tons of fuel wood and that the total annual production of fired clay bricks in the is the country was estimated to be about 2.8 billion. This is mainly produced by traditional methods where biomass fuels are used for brick burning (Alam, 2006).

According to Maithel (2008), the Asian brick industry consumes 110 million tons of coal per annum. This one hundred and ten million tons of coal alone produces some 180 million tons of carbon dioxide. According to Kumbhar, *et al*. (2013), India consumes about 35 million tonnes of coal annually emanating from more than 100,000 brick kilns producing about 250 billion bricks annually. In Pakistan, brick production accounts for 54 % of all coal consumption.

2.5 Contribution of brick making to greenhouse effect

Global warming has become the main concern of environmentalists as well as other stakeholders (Alam & Starr, 2009; Sampe & Pakiding, 2015). Brick making also in a way is contributing to global rising temperatures. Each tree cut down for fuel reduces the environmental capacity to absorb carbon dioxide a greenhouse gas; thus increasing its greenhouse effect. According to Ahimbisibwe, *et al*., (2016), the average energy consumptions by small-scale brick producers in third world countries are up to 5 times more than the average energy required for brick production in developed countries This is because developing countries rarely seek sustainable fuel sources like coffee husks or sawdust that have been adapted to fuel larger commercial kilns, as such small-scale producers by comparison target naturally occurring indigenous species. According to

Dalain, *et al*., (2013), brickfields are the important contributors of the emission of greenhouse gases in Bangladesh as they burn huge amounts of coal and wood fuel. Further Dalain, *et al*., (2013), noted that the main pollutants which are emitted from the brickfields are Particulate Matter (PM), some hazardous gases like carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxide (NO) and supher dioxide (SO_2).

Further dry brick kiln dust appears to cause little damage if deposited on a leaf surface, yet in the presence of moisture; such dust imparts damage and consequential growth inhibition to plant tissues. Dust coating of leaves reduces photosynthesis and the increased plugging of stomata reduces. Usually the PM concentrations are in low concentration in most brick fields, but they have long term massive impact on global environments as well as on human health.

2.6 Effect of brick burning to human health

It is important to note is that some hazardous gases like Sulfur dioxide (SO_2) tend to irritate the mucous membrane of the respiratory track and foster the development of chronic respiratory diseases, particularly bronchitis, pulmonary emphysema and asthma. Individuals who suffer from chronic respiratory diseases may experience coughing and a difficulty in breathing when the SO_2 concentration rises (Dalain, *et al*., 2013). This point is supported by Das, (2015), who writes that workers engaged in brick manufacturing such as raw brick, loading and unloading of raw brick-kilns, firing of coal (rushing, fuel charging) are under various thermal and physiological stresses due to extremely unhygienic conditions prevailing in brick kilns. Further, workers are exposed to tuberculosis, asthma and respiration problems. It is also important to know that dust laden atmosphere is potential health hazard leading to pneumoconiosis or related pulmonary disorder depending on particle size and concentration of dust particulate matter, duration of exposure and composition of dust particles (Das, 2015).

2.7 Climate change and forests use

Climate change is a global environmental problem. It is however, a contentious issue regarding its occurrence and causative factors. Much as there are different schools of thought regarding the concept of climate change, human induced changes to the global carbon cycle are thought to be the main driver of climate change that has occurred since the industrial revolution and which is predicted to accelerate over the next century Reid, *et al.,* (2004). Primarily, the expansion of agriculture activities and use of forests for fuel and timber, have led to significant reductions of these forests which act as carbon sinks. Continuing deforestation, for instance in the tropical regions, is currently thought to be responsible for annual emissions of 1.1 to 1.7 billion tonnes of Carbon which is approximately 20% of anthropogenic CO_2 emissions (Reid, *et al.*, 2004).

It is important to acknowledge that there is strong evidence that sustainably managed natural forests can be important carbon sinks. Evidence from experiments across a range of forests from tropical, temperate and boreal regions show that forests are currently a net sink of CO_2, absorbing up to 25% of global fossil fuel emissions (Reid, *et al*., 2004).
Africa has been identified as one of the continents most vulnerable to the impacts of climate change (Coumou, *et al*., 2016; Thompson, *et al*., 2010**)**. In the case for Malawi, the repercussions of climate change are being felt in various ways like frequent occurrence of extreme heat events, increasing aridity and changes in rainfall patterns in some areas. In Malawi, agriculture plays a crucial role both the subsistence and national levels. As such an unreliable rainfall pattern threatens the livelihoods of a large proportion of the population which currently depend on agriculture. Drier conditions are also affecting the river catchment areas which have led to most rivers drying easily (Thompson *et al*., 2010**)**.
With the realisation that forests are vital for many other reasons including acting as sinks for carbon dioxide, deliberate efforts have to be employed towards sustainable management of forests.

2.8 Significance of indigenous trees

Malawi forests are mostly dominated by miombo woodlands. Throughout the miombo region, the woodlands supply many products and services essential to the well-being of rural communities. One important aspect is that they contain diverse fruit types. Many fruits are a major source of iron and some, particularly *Parinari curatellifolia*, have a high crude protein and calcium content. These fruits also protect rural poor farmers in times of famine as wild fruits are consumed mainly in the hot dry season and early rainy season before the cultivated crops are ripe (Campbell, 1996). In some cases people hunt from these forests meat from wild animals such as antelope and hares has long been an important source of protein for rural dweller (Campbell, 1996).

Where formal health services are not readily available, traditional healers are consulted and they depend on these indigenous trees most of the time. The indigenous forests are also the primary source of energy, in the form of firewood and charcoal, poles and construction products, timber, materials for tool handles and household utensils. Indigenous trees also act as catchment areas of most important rivers like some of the major rivers in southern, central and eastern Africa originate from areas covered by miombo woodland, most notably the Zambezi River (Syampungani, *et al*., 2009; Campbell, 2009).

2.9 Exotic trees usage and repercussions

Malawi, like many countries in Africa and the world, has different exotic tree species. Some of these include *Gmelina* arborea, *Eucalyptus camaldulensis* and *Senna spectabilis.* These exotic trees are very helpful as they help with timber, poles, fuel wood, oil among others (Zhang, 2012). Among these exotic trees eucalyptus is among the most preferred trees, as it grows fast and survives in marginal environments in most parts of the world (FAO, 2009). According to (Zhang, 2012), Eucalyptus is a kind of evergreen trees, which was indigenous to Australia, Indonesia and Philippines, and has 100 subspecies or varieties which are economically important.

However, since its introduction, Eucalyptus has been marred by controversies, surrounding its alleged negative environmental impacts and inability to provide the necessary productive and ecological services. As a result, in some cases, its promotion and planting was banned altogether (FAO, 2009). Among the concerns are its impacts on the environment, like removal of too much water from streams and underground water, adverse effects of their leaf litter on soil humus, heavy consumption of soil nutrients, the inability to prevent soil erosion, inhibition of growth of other plants and failure to provide food supplies or adequate habitat for wildlife (FAO, 2009). According to Noble, *et al*., (1996). *Eucalyptus* species have substantial and vigorous tap root systems which are able to reach depths of more than 20 m. This gives it leverage with regard to tapping underground water.

In this case the use of fast growing plantation species such as eucalypts is inevitable as they are preferred to other species. In this case, there is need for deliberate effort to support the land users and policy makers in selecting the right species for the specific sites. This will help land owners to be fully informed about the use of these exotic species which in return will help lessen the drawbacks of these exotic trees. Once shortcomings of these exotic species are lessened, the benefits will be augmented.

2.10 Classification of Brick Kilns

Brick Kilns are usually classified depending upon the nature of production process; typically brick kilns can be classified as intermittent kilns and continuous kilns (Dalain, *et al*., 2013).

2.10.1 Intermittent kilns

In intermittent kilns, bricks are fired in batches; fire is allowed to die out and the bricks are allowed to cool after they have been fired. The kiln is emptied, refilled and a new fire is started for each batch of bricks. The heat trapped in the bricks and the kiln is lost during cooling, making this a fuel-inefficient technology (Basu, *et al*., 2016). Examples of intermittent kiln type include Clamps which were common in the study area and also predominantly used in most parts of Malawi.

2.10.2 Continuous kilns

In a continuous kiln fire is always burning and bricks are being warmed, fired and cooled simultaneously in different parts of the kiln. Fired bricks are continuously removed and replaced by green bricks in another part of the kiln which is then heated. Continuous kilns utilize heat from the cooling bricks and combustion air to pre-heat green bricks or dry bricks before they are put into the kiln, making them more fuel efficient. Due to incorporation of heat recovery features, continuous kilns are more energy efficient (Basu, *et al*., 2016).

2.11 Classification based on air flow

Based on the direction of air flow with respect to the brick setting in the kiln, brick kilns can be classified as up draught kilns, down draught kilns and cross draught kilns.

2.11.1 Up-draught kilns

In an up-draught kiln, air enters the kiln from below, gets heated from the fire and moves upward through the brick setting transferring the heat to the bricks. The upward movement of heated air is a natural phenomenon and it does not require a stack or fan to cause the air flow. Clamps and vertical shaft brick kiln (VSBK) are examples of up draught kilns (Darain, *et al*., 2013; ESMAP, 2011).

2.11.2 Down-draught kilns

In a down-draught kiln, air is first heated up with the fire. The hot air is then made to enter the kiln from top and is brought down through the brick setting with the help of draught created by a stack. In this type of kilns, usually bricks are not in the direct contact with fire (ESMAP, 2011).

2.11.3 Cross-draught kilns

In cross-draught kiln, air flows horizontally through the brick stacking. The air movement is caused by either the draught created by the chimney (natural draught) or the draught provided by a fan (forced draught). These are also called horizontal draught kilns (Darain, *et al*., 2013).

2.12 Kiln technology Used in Malawi

Much as diverse Kiln Technologies exist, the dominant Kiln technology used in burning bricks in Malawi is the clamp type which is an example of intermittent technology. This is a very old aged method of brick production process. The clamp is the most rudimentary type of kiln. A flat dry land is chosen as a site for the construction of a clamp. The bricks are stacked in alternate layers to reach the desired height, gradually tapering towards the top. The base of the clamp is rectangular with tunnels. The top surface is covered with earth to prevent the escape of heat as they use fuel wood as source of energy. Several types of fuels such as firewood, coal, coal powder, agricultural waste, and discarded tyres may be used. To protect heat energy loss mud is smeared outside the clamp kiln during the initial process of fire lighting.

2.13 Economic Benefits of Brick Making

The traditional brick making industry has a positive influence in supporting construction development and source of income for micro and small scale business owner as well as create employment for uneducated and unskilled labour (Alam & Starr, 2009). This sentiment is supported by (Abdallah, 2015), who writes that during dry season, when the soils of the plains in northern India provide no work, millions of small farmers and landless agricultural workers migrate to the brick kilns in North India and Nepal for six months to work as moulders and firemen in brick kilns. The same is also echoed by (Maithel, 2008), who writes that in Asia traditional brick making sector provides livelihood to hundreds of thousands of poor people.

2.14 Legal, Policy and Institutional framework for Environmental Protection in Malawi

Malawi as a country is cognisant of the importance of the environment; this is ably epitomized in important legal and policy instruments like NEP and EMA. The mandate for proper management of the environment emanates from the Constitution of the Republic of

Malawi as a supreme document under section 13 (d) which provides the principles of environment management as follows: "*To manage the environment responsibly in order to prevent the degradation of the environment; provide a healthy living and working environment for the people of Malawi; and accord full recognition to the rights of future generations by means of environmental protection and the sustainable development of natural resources*". The way natural resources are being unsustainably exploited especially the indigenous forests through diverse uses, actually raises questions if the recognition to the rights of future generation is still being considered

As a buildup on the constitution of Malawi on the need for sustainable use of resources the Environmental Management Act (EMA), (2017), as an Act to make provision for the protection and management of the environment and the conservation and sustainable utilization of natural resources clearly stipulates that, it shall be the duty of every person to take all necessary and appropriate measures to protect and manage the environment. It also emphasizes conservation of natural resources and promote sustainable utilization of natural resources.

Importantly, EMA recognizes that "natural and genetic resources of Malawi shall constitute an integral part of the natural wealth of the people of Malawi and shall be protected, conserved and managed for the benefit of the people of Malawi; and save for domestic purposes, shall not be exploited or utilized without the prior written authority of the Government". Much as EMA encourages authorization from government before exploitation of resources save for domestic purposes, in most cases this is not the case these days when it comes to exploitation of resources like indigenous exploitation of forests.

Much as the institutional framework for environmental management is set through the Environmental Management Act (1996), the current Institutional Framework is highly complex due to the number and size of the institutions involved in administering environmental affairs. This includes confusion about responsibilities and a general lack of awareness of cross-cutting environmental issues and how to include them into project design. In addition, the delivery of environmental management services is fragmented across NRM sector ministries dealing with environmental issues, resulting in a lack of coordination (Halle & Burgess, 2006).

For proper guidance on all aspects of environmental management, the constitution of Malawi provides principles for national policy; exemplified in the National Environmental Policy (NEP) which in a way helps fill the gaps or rectify the inconsistencies in the environmental management process. For instance, NEP encourages holistic approach to environmental management as one of its broad goals by ensuring cooperation between government, local communities, non-governmental organisations and the private sector in the management and sustainable utilization of the natural resources and the environment.

It is for this reason that we have Village Natural Resources Management Committees (VNRMC), District Environmental Committees (DEC) reflecting this decentralization of natural resource management. Various legal and policy instruments also promote the decentralization of resource management like EMA, National Decentralization Policy (NDP) and the Local Government Act (2010), Forestry (Amendment) Act (2017), and National Resources Management Policy and Strategy (NRMP) intended to foster coordination at the local and district level in environmental decision making and management.

Though the government has drawn attention of people to conserve their environment through planting trees in their areas for fuel wood and other needs, still people continue cutting trees from the nearby forests for many purposes. Given the pressure on forests and firewood, there is a keen interest of the government in the building materials sector. Government has developed a policy to ban use of firewood for brick burning and promoting concrete blocks (Darain, *et al*., 2013). However, in absence of viable options, banning the use of forest resources is proving difficult.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the study area, tools and methods used in data collection, data entry and analysis.

3.2 Description of Study area

The study was done in six villages within Zomba city. These villages were Mapalo (in Domasi area), Kapile village at Songani, Chombe village at Jokala, Kundende village at Airwing and Nambesa and Mingu at Jali area. Amongst many, these are some of the areas within and outside Zomba city where brick-making is mostly done as an enterprise. The areas provide ready market for urban constructors. The map (Figure 3.1) shows the villages where kilns were sampled for the purpose of the study.

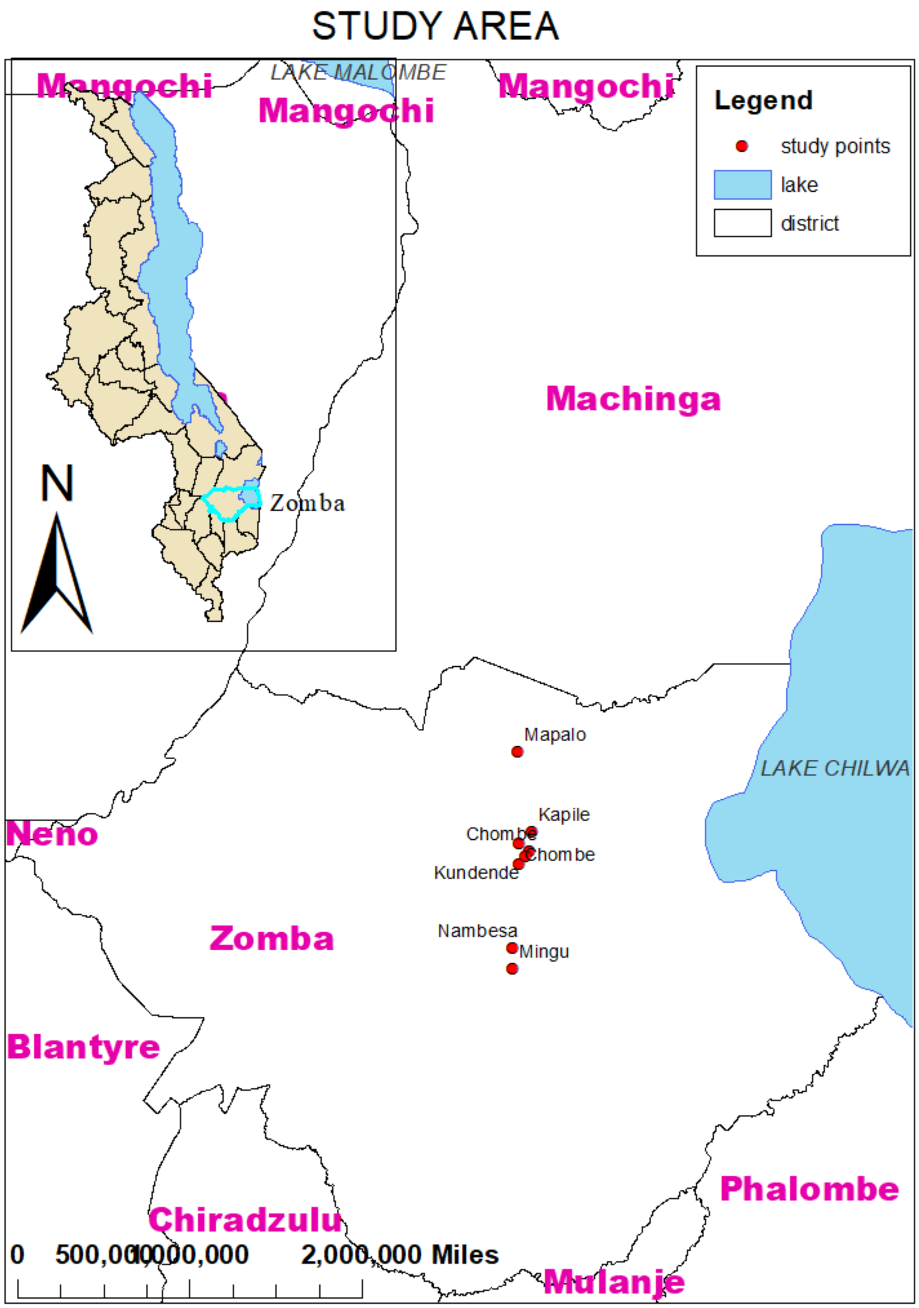

Figure 3.1: The study area within Zomba in Malawi

3.3 Climate, Geology and Soils in the study area

Zomba has diverse topographic characteristics that generate a vertical and horizontal variety of climatic zones between different areas of the District. Zomba experiences a tropical climate with three main seasons–cold-dry, hot-dry and hot-wet, ranging respectively from April to July, August to October and November to March. The geology of Zomba District is also very diverse. Generally, the base complex is composed of metamorphic rocks derived from sedimentary and igneous rocks of Precambrian origin. The Plains surrounding Lake Chilwa are characterized mainly by sandy and rocky solid that show some stratification. Being agriculture based, people in the study area mostly rely on unpaid work, dominant in the large agricultural sector, with uncertain future earnings (Zomba District Assembly, 2009).

The soils in Zomba district are mostly well-drained, yellowish-brown to reddish-brown, medium to fine textured and slightly medium acidic and of great depth. Generally, soils in the district can be grouped as lithol soils for the high areas and ferrigenous soils for the low-lying areas. West of Lake Chilwa, moderately deep sandy soils occur over either ironstone or soil parent materials with a high percentage of ironoxides or concretions. Generally, the overall type and texture of the soils in the low lying areas are suitable for intensified agriculture. The upland soils, though less fertile, are suitable for developments in agro-forestry, riverine farming. In general, the soils in Zomba district are moderately fertile, with the fertility rising with the proximity to either Zomba Plateau or Lake Chilwa. Due to deforestation and agricultural practices, soil erosion has become a rising concern (Zomba District Assembly, 2009).

Vegetation is characterized by Miombo woodlands on the plateau, hills and escarpments, and Mopane woodlands, which are largely dominated by Colophospermum Mopane with open glades, cover the fringes of the district. These woodlands tend to be associated with mopanosol soils and compact alkaline soils with unstable structural characteristics resulting in a low level of cultivation. Woodlands consists of natural tree species like Brachystegia *stipulata*, Brachystegia *manga*, Brachystegia *speciformis* and Jusbemadia *globifora* (Zomba District Assembly, 2009).

3.4 Sampling Methodology

The study used Convenience Sampling to identify brick-kilns as the targeted population. Convenience sampling is a type of nonprobability or nonrandom sampling where members of the target population that meet certain practical criteria, such as easy accessibility, geographical proximity, availability at a given time, or the willingness to participate are included for the purpose of the study. It is also referred to the researching subjects of the population that are easily accessible to the researcher (Etikan, *et al*., 2016). He further argues Etikan, *et al*., (2016), that convenience sampling may include data taken near camps, around parking areas, or on areas where density is known to be high. Biologist often use convenience sampling in the field work because it is easier like walking on a road and stop occasionally to record numbers. Convenience sampling in this study was useful as brick-kilns as population of study with predefined elements were targeted. The vital elements included length, width and height.

Prior to choosing the brick-kilns to be studied; a visit to the study site was made before hand on dairy basis for the following reasons. Firstly, to spot where fuel wood has been offloaded in readiness of burning the brick-kiln. Middle-men helped in spotting where fuel wood was offloaded. Secondly, to verify if the brick-kiln was different in terms of size from the already visited kiln or kilns. Thirdly, to seek consent from owners of brick-kilns before measuring and identifying the species they used in burning bricks.

3.5 Data Collection tools

3.5.1 Literature Search

A rigorous literature search was done on relevant existing information on use of fuel wood in burning bricks. The search included books, policy documents, journals and environmental reports. The internet also proved handy in supplementing the information considered relevant to this study.

3.5.2 Questionnaires use

A questionnaire with kiln parameters like kiln number, location, length and height, Coordinates for GPS and tree log parameters like log identification, wood type whether plantation or indigenous was used to collect data.

3.5.3 Consultation with experts

For technical and professional information, experts from Forest Research Institute of Malawi (FRIM) and National Herbarium and Botanic Gardens (NHBG) were consulted. A Botanist was used in determining local and scientific names of tree species. FRIM experts helped with log measurements and important formula to use in quantification of wood volume.

3.5.4 Identification of tree species

During data collection the Botanist accompanied the data collection team and physically identified the merchantable tree species.

3.6 Materials used

The Global Positioning System (GPS) was used to pin point the actual coordinates for each sampled brick kiln. This helped in determining the exact locations of brick-kilns and helped in generation of a map of the study site.

A caliper was used to measure mid -diameter over – bark for each log. A linear tape was used to measure the length of each log.

Figure 3.2: Caliper and linear tape being used to measure mid-diameter and length of the log

3.7 Quantification of wood volumes per kiln

To determine the amount of wood used to burn a specific soil volume (for the entire brick kiln) the following formula was used:

Total wood volume per kiln is a summation of independent log volume per kiln in question as represented by the Huber's formula (Tewari & Singh, 2005):

$$V = \frac{\pi(d_m)^2}{4} L$$

……………………………………………..(1)

d_m = diameter at mid-length of log (m)

L = log length (m)

V = volume of log (m^3)

During field work, mid diameter was determined in centimeters (cm) while length of the Log was quantified in meters (m). As such to adapt to Huber's formula centimeters (cm) were changed to meters (m).

i.e. $Total\ wood\ volume\ (V) = \frac{\pi(d_m)^2}{40000} L\ , where\ d = mid - diameter\ of\ the\ \log(cm)$

3.8 Determination of Total Soil Volume per Kiln.

It was important to determine soil volume per kiln. Total soil volume gave us the amount of soil which was actually burnt by the total wood volume. The following formula was used to determine the soil volume:

$$[(Volume\ of\ kiln\ base) + (Volume\ of\ kiln\ trapezoidal\ part)] - [Total\ hole\ volume]$$

Where: Volume of kiln base = $(l\ x\ wx\ h)$

Volume of the kiln trapezoidal part = $\left(\frac{1}{2}(a+b)h\right)x\ L$ ……………………………………..(2)

Total Kiln hole volume $= (Hole\ area\ x\ kiln\ width)n, where$ "n" $number\ of\ holes\ per\ kiln.$

To find the estimated soil volume burnt, total hole volume was subtracted from total kiln volume. Total hole volume in the base of the kiln represented the void of the kiln. The voids are the areas where firewood are inserted and burn. Heat energy is transferred from these areas to the rest of the kiln, thereby burning the entire kiln

3.9 Correlation analysis Using Pearson's Correlation Coefficient

In this study, a *linear product-moment correlation coefficient* (also known as Pearson's correlation coefficient) was used to express the strength of the relationship between wood volume used to burn bricks and the actual soil burnt in the study area. This coefficient is generally used when variables are of quantitative nature, that is, ratio or interval scale variables.

$$r = \frac{n\sum xy - \sum x \sum y}{\sqrt{\{n\sum x^2 - (\sum x)^2\}\{n\sum y^2 - (\sum y)^2\}}} \quad \text{……………………………..(3)}$$

The value of r always lies between –1 and 1 inclusive, that is, $-1 \leq r \leq 1$. If y increases when x increases proportionally, it implies a positive or direct correlation between them. However, if y decreases when x increases (or vice versa), then it is said that they are negatively or inversely correlated. This maintains that the extreme values of r, that is, when $r = \pm1$, indicate that there is perfect (positive or negative) correlation between x and *y*. However, there is a no or zero correlation if r=0. *Pearson's correlation coefficient* measures linear relationship only unlike non-linear relationships.

3.10 Determination of calorific value for tree species

Calorimetry was used to determine the energy content of tree logs (species) in the study area. A Parr 6200 calorimeter with Parr 6510 water handling system was used. This machine can achieve the highest level of precision and accuracy of any oxygen bomb calorimeter. A well-grounded sample in the range of 0.2700-0.3000g masses was weighed in the bomb crucible and loaded into a bomb with a string tied on it. Then the bomb was filled with oxygen gas until it automatically closed the gas supply. The packed sample in the bomb was loaded into the machine and sample run for calorific energy value. After exactly 16 minutes, the machine gave the value for the sample that was loaded in.

3.11 Data Analysis

Microsoft excel was used for data entry, sorting, selecting data subsets and data manipulation and for producing graphs. SPSS was used for data analysis including determination of the Pearson's correlation coefficients

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Introduction

Fifteen brick-kilns were targeted for the study but the researcher only managed to assess 8 brick-kilns due to the fact there is a myth in the study area that unknown people are not allowed to touch fuel-wood or brick kilns before the burning process as it is believed that this affects the quality of the burnt bricks. In this regard some brick-kiln owners accepted and others rejected the researcher to carry out the study on their brick-kilns. The results are presented corresponding to the specific objectives.

4.2 Quantification of wood volume in production of fired clay bricks used per brick-Kiln in the study area

It was important to determine wood volume used per kiln against soil volume so that usage is correlated in line with soil volume burnt. Also this was vital in helping determine the bigger picture of wood usage assuming we have more brick –kilns.

Table 4.1: Amount of wood volume (m^3) used to burn a specific amount of soil volume per kiln (m^3). Source: Author's computation.

KILN NO	TOTAL KILN VOLUME (m^3)	TOTAL HOLE VOLUME (m^3)	TOTAL SOIL VOLUME BURNT (m^3)	TOTAL WOOD VOLUME USED/KILN (m^3)
1	54.8	5.4	49.4	5.8
2	83.6	8.3	75.3	3.2
3	69.1	2.8	66.2	2.1
4	23.9	1.4	22.5	1.7
5	188.1	10.5	177.6	7.6
6	20.4	1.6	18.8	1.4
7	43.0	3.8	39.1	2.0
8	37.3	4.3	33.0	1.9
		TOTAL	**482**	**26**

Different kiln sizes were purposefully visited to determine how differential soil volume would determine the usage of the amount of wood volume to use. Table 4.1, shows, cumulatively across the kilns, approximately, 482 m^3 of soil volume was burnt using 26 m^3 of wood volume. The results in Table 4.1, show for instance for Kiln 1 of total soil volume burnt was 49.4m^3 using 5.8 m^3 while for kiln 5, the total soil volume of 177.6m^3, was burnt using 7.6m^3. With reference to Kiln 1 and 5, it showed positive correlation where kiln 5 with bigger soil volume was burnt by more wood volume compared to kiln 1 which had less soil volume and used lesser wood volume.

4.3 Correlation analysis

In this study, a moderate positive relationship between the amount of soil burnt and total would volume used to burn it was realised. Figure 4.1 shows a scatter plot of the study variables

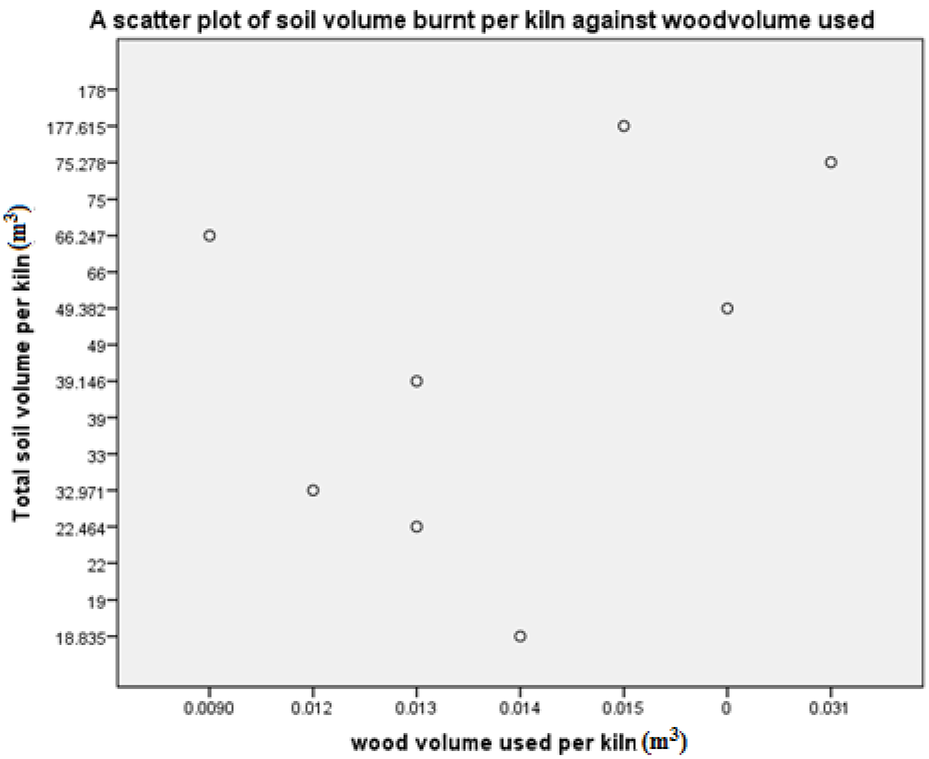

Figure 4.1: a scatter plot of wood volume used to burn a specific soil volume in the study area.

Table 4.2 : *Results of correlation between total soil volume burnt per kiln and the total wood volume used to burn it*

Correlations

		Total soil volume per kiln (m^3)	wood volume used per kiln (m^3)
Total soil volume per kiln (m^3)	Pearson Correlation	1	.152
	Sig. (2-tailed)		.719
	N	8	8
wood volume used per kiln (m^3)	Pearson Correlation	.152	1
	Sig. (2-tailed)	.719	
	N	8	8

Table 4.3 : Model summary for the relationship between soil volume burnt per kiln (m^3) and the total wood volume used to burn such soil.

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.152[a]	.023	-.140	54.862

a. Predictors: (Constant), wood volume used per kiln (m^3)

b. Dependent Variable: Total soil volume per kiln (m^3)

Using SPSS, the Pearson's correlation coefficient (*r*) = 0.152 was determined in this study at 0.719 significance level (Table 4.3). This gave a coefficient of determination (i.e. simply the square of the correlation coefficient) (r^2) = 0.023 (Table 4.3). Referring to the kilns visited, assuming all the wood came within the study area, it implies that 2.3% of the wood cleared in the study area is due to brick burning. If more kilns were visited in the study area, a greater percentage of wood clearance wood be achieved. This implies that apart from burning bricks which demands usage of fuel wood, there are other factors which also influence the clearing of forests. Some of these factors may include, domestic fuel wood for cooking, charcoal making and others.

.

Table 4.4 : Coefficients of Linear regression obtained from SPSS for this study

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	42.237	51.535		.820	.444	-83.864	168.339
	wood volume used per kiln (m^3)	1125.302	2984.093	.152	.377	.719	-6176.511	8427.114

a. Dependent Variable: Total soil volume per kiln (m^3)

Therefore, basing of the coefficients of Linear regression (Table 4.4), it can be concluded that at 95% confidence interval (p=0.05), there is a huge range of wood volume clearance (-6176.5m^3, 8427.1m^3) used to burn bricks in the study area (referring to the kilns visited) in Zomba.

However, the study has revealed that it is not always that there is a direct correlation between wood volume and soil volume burnt, where bigger soil volume will directly correlate to equally larger wood volume use. It is evidenced in this study with reference to Kiln 1 which had total soil volume of 49.4 m^3 yet relatively used far much higher total wood volume of 5.8 m^3 compared to Kiln 2 and 3 which had higher soil volume of 75.3 m^3 and 66.2 m^3 respectively, yet they used lower wood volume of 3.2 m^3 and 2.1 m^3 respectively, which was far much lower compared to Kiln 1 of 5.8m^3.

This may be attributed to various factors like the amount of wood used to burn bricks being arbitrarily chosen/estimated individually. This statement is also echoed by Zingano, (2005), who calculated energy content from wood required to burn bricks, who argues that 1000 bricks require 0.7 tonnes of firewood. However, the variation from 5.7 – 12.9 MJ per brick can be explained by the fact that there is no agreed criterion for a burnt brick. The bricks that are considered ready range from under burnt to over burnt bricks. Additionally, the variability may also depend on the ease of accessibility of firewood to the particular individual. It is also important to note that there is no any defined yardstick to determine the amount of wood for a specific size of brick kiln apart from the usual approximation method used by local brick burners. To that end, it is possible to overestimate the wood volume for a specific kiln or equally underestimate.

It is also vital to know that the amount of wood used for a successful burning of bricks in a specific Kiln may also partly depend on the chemical characterizes of the soil. Some soil types may demand high amount of wood to be burn unlike others as some have high moisture content, among other factors (VEBK, 2008). Furthermore, the type of Kiln design also contribute to amount of wood used to burn a specific soil volume. The clay brick firing process may be classified based on the structure of the firing system adopted either intermittent or continuous. Intermittent kilns include clamp kilns, scotch Kilns, round Kilns, annular Kilns, zigzag-Kilns (Akinshipe & Kornelius, 2017). Malawi as a country, the predominantly used Kiln when firing clay bricks is the clamp Kilns. Clamps are primitive or traditional Kilns, lacking a permanent structure. They are referred to as such because they are so energy inefficient. Lack of permanent structure entails that every time the Kiln is burnt, it is allowed to cool down, and in the process some energy is lost contributing to energy inefficiency. In other countries , especially developed countries brick firing has evolved beyond ancient, traditional, basic and common techniques, to more sophisticated, energy efficient technologies like the use of continuous Kilns where bricks pass through a stationery firing zone like tunnel Kilns (Akinshipe & Kornelius, 2017). Stationary firing zone ensures continuous heating process which contributes to its energy efficiency.

Worse still, there is no any specific line of measurement/scale to mark the successful burning and end the brick burning process (or stop applying firewood to the kiln). Currently, most people approximately use the attainment of a "brick-red" colour as an indicator in order to determine if the bricks have been successfully burnt. However, this may be problematic for different people as they differently judge the level of burning. This is attributable to the use of variable amount of firewood for a specific volume of soil burnt. The bricks that are considered ready range from under burnt to over burnt bricks.

Overestimation of wood volume needed in burning bricks might be an important parameter contributing to high levels of deforestation and clearance of forests in communities where bricks are being produced and burnt in Malawi. Apart from this anomaly where a kiln of low soil volume used higher wood volume, the other kilns followed positive correlation.

4.4 Assessing the diversity of tree species used in firing clay bricks in the study area

The study found out that different tree species both indigenous and exotic were used in burning fired clay bricks in the study area. The study revealed that there were 33 different tree species used in burning bricks in the study area. They were 25 Indigenous tree species of which 6 were fruit tree species; 8 Exotic tree species of which 3 were fruit trees.

The results of this study show that much as the number of indigenous tree species outnumbered the exotic ones; comparatively and cumulatively, the study determined that wood volume for both exotic (10.6 m^3) and indigenous (10.8 m^3) was used as shown in Table 4.5.

Table 4. 5 : Total wood volume for indigenous and exotic trees used per brick kiln

KILN	Total Wood volume used/kiln (m^3)	Total Wood volume for indigenous (m^3)	Total Wood volume for exotic type (m^3)
1	4.53214331	3.455004703	1.077138608
2	2.505555157	2.144830273	0.360724884
3	1.666130989	1.536523993	1.30E-01
4	1.344285993	1.42E-01	1.201931945
5	5.930045161	1.62E-01	5.768538048
6	1.123374975	0.78857083	3.35E-01
7	1.57E+00	6.42E-01	0.929019392
8	1.471453063	1.21E+00	2.59E-01
	Total wood volume	10.08	10.06046496

A huge number of the indigenous species types as compared to the exotic ones signify these indigenous tree species are more sort after. This accelerated pressure on indigenous trees may further negatively affect the community's environmental benefits from such trees. For instance, the clearance of the indigenous trees may impede river flows in the area; abridged nutritive value of the trees and forests, since some of the fruit trees were also cut for brick burning like *Uapaca kirkiana*. High deforestation of indigenous tree species also reduces the economic value of the land and leads to acceleration of soil erosion (Malawi Environmental Outlook, 2010). Table 4.6 and Appendix 2 shows different tree species used per kiln.

Table 4.6 : Tree species Volume and Percentage. Source: Author's computation

Tree species	Volume	% volume used
Mangifera indica(Mango)	8.78	43.59483615
Acacia polyacantha (Nthethe)	3.455	17.15491559
Julbernardia globiflora (Mchenga)	1.65	8.19265144
Persea americana(peyala)	1.23	6.107249255
Uapaca kirkiana (Masuku)	8.84E-01	4.389275074
Khaya anthotheca (M'bawa)	7.89E-01	3.917576961
Brachystegia boehmii (Mombo)	5.82E-01	2.889771599
Gmelina arborea (Malaina)	4.23E-01	2.100297915
Newtonia buchananii (Mkweranyani)	2.65E-01	1.315789474
Albizia glaberrima (Mtangatanga)	2.18E-01	1.082423039
Toona celiata (Sendeleya)	2.12E-01	1.052631579
Pterocarpus angolensis (Mlombwa)	1.84E-01	0.913604767
Diplorhynchus condylocarpon (Thombozi)	1.46E-01	0.724925521
Casimiroa edulis (Masuku a chizungu)	1.44E-01	0.714995035
Lannea discolor(Chiumbu)	1.40E-01	0.695134062
Parinari curatellifolia (Maula)	1.23E-01	0.610724926
Terminalia Sericea(Naphini)	1.15E-01	0.571002979
Diospyros kirkii (Mchenje)	9.50E-02	0.471698113
Vitex payos (Mpysipysa)	7.26E-02	0.360476663
Brachystegia bussei (Mtwana)	7.16E-02	0.35551142
Kirkia acuminata (Mtumbu)	5.73E-02	0.284508441
Eucalyptus camaldulensis	5.37E-02	0.266633565
Cordia abyssinica (Msingati)	4.76E-02	0.236345581
Senna spectabilis (Kesha wa Maluwa)	4.11E-02	0.2040715
Annona senegalensis (Mpoza)	3.32E-02	0.164846077
Acacia galpinii (Nkunkhu)	2.64E-02	0.131082423
Pterocarpus rotundifolius (Matakale)	2.42E-02	0.120158888
Senna petersiana (Ntowa)	2.37E-02	0.117676266
Philenoptera bussei (Chimpakasa)	1.67E-02	0.082919563
Faurea saligna (Chisese)	1.61E-02	0.079940417
Combretum zeyheri (Kadale)	1.05E-02	0.052135055
Pericopsis angolensis (Muwanga)	5.61E-03	0.027855015
Uapaca nitida (Katsokolowe)	2.47E-03	0.012264151

As shown on Table 4.6 it was important to determine the percentage and volume to give an indicator of the most used tree species. The study showed that *Mangifera indica* an exotic fruit tree was the most used at 43.5%, followed by *Acacia polyacantha (Nthethe)* at 17.1%, *Jubernadia globiflora (Mchenga)* at 8.1% and others with smaller percentages. The dominant usage of *Mangifera indica* a fruit tree should be a source of concern. Fruit trees are important regarding livelihood of most people.

4.5 Determination of Calorific Value (CV) for tree species

The Calorific Value (CV) of a total of 33 tree species was determined in the study area, which comprised exotic and indigenous species. In each subcategory, there were both fruits and non-fruit trees. It was determined that indigenous non-fruit tree species had the highest average calorific value of 47,657,453.36 with values ranging from 43,576,691.89-53,705,934.735). The lowest average calorific value was determined in exotic fruit tree species of 47,095,764.96 with values ranging from (45,908,689.55-47,699,400.805) as shown in Table 4.7.

Table 4.7 : Calorific values (CV) of tree species

		Calorific Values(CV) (J/Kg)		
		Overal mean CV	**minimum CV**	**maximum CV**
exotic	fruits	47,095,764.96	45,908,689.55	47,699,400.81
	non-fruits	47,373,591.95	45,137,746.72	49,392,106.82
Indigenous	fruits	47,247,591.99	44,273,597.17	49,165,646.57
	non-fruits	47,657,453.36	43,576,691.89	53,705,934.74

The Indigenous non-fruit tree species with highest Calorific value was *Pterocarpus rotundifolius* (Sond) Druce (*Matakale*) with 53,705,934.735 J/Kg and the indigenous tree species with the lowest CV of 43,576,691.89 was *Newtonia buchananii (Baker) G.C.C. Gilbert & Boutique* (*Mkweranyani*). For indigenous fruit tree species, the tree with the highest CV was *Uapaca nitida Mull.Arg* (*Katsokolowe*) with a value of 49,165,646.57 J/Kg and the indigenous fruit tree with the lowest CV was *Vitex payos* (Lour) Merr (*Mpysipysa*) with a value of 44,273,597.17 J/Kg.

The exotic non-fruit tree species, the tree with the highest CV was *Albizia glaberrima* (Schumach & Thonn) Benth (*Mtangatanga*) with a value of 49,392,106.82 J/Kg and the exotic non-fruit species with the lowest CV was *Toona celiata M.Roem* (Sendeleya) with a value of 45,137,746.72 J/Kg. For exotic fruit tree species, the tree with the highest CV was *Persea americana Mill (peyala)* with a value of 47,699,400.81 J/Kg and the tree with the lowest CV was *Casimiroa edulis Llave and Lex (Masuku a chizungu)* with a value of 45,908,689.55 J/Kg.

All the 33 tree species in the study area (both exotic and indigenous), the tree with the highest CV was *Pterocarpus rotundifolius* (Sond) Druce (*Matakale*) with 53,705,934.735 J/Kg, which is a non-fruit indigenous tree species.

However with reference to minimum CV with reference to Table 4.7, it was *Newtonia buchananii (Baker) G.C.C. Gilbert & Boutique,* an indigenous non –fruit tree species that had the lowest of all species of 43,576,691.89 J/Kg. This is important to know in the sense that, there is a common belief that almost all indigenous tree species have higher CV compared to exotic tree species, yet *Albizia glaberrima* (Schumach & Thonn) Benth (Mtangatanga) with a CV value of 49,392,106.82 J/Kg is far much higher as an exotic non-fruit tree species.

Regarding the CV range (Table 4.7), indigenous non-fruit tree species have wider margin, signifying huge disparity in terms of CV amidst non-fruit indigenous tree species, compared to exotic tree species which show minimal disparity, signifying minimal difference in terms of CV amidst exotic tree species.

Comparatively, the study done by Zingano, (2005), who analysed energy content of some tree species (Table 2.2), there are remarkable differences to what was found. With reference to Brachystagia species as an example, energy content of 21.5 MJ is far much lower compared to 48MJ (Tables 4.7). Important to note is that *Brachystagia* species are part of Miombo woodland (Abdallah & Sauer, 2007). Miombo woodlands make up a significant proportion of total forested land in Malawi and other countries. As such most indigenous species are in the category Brachystagia species. Additionally, contrary to what Zingano, (2005), got, in this study, some exotic tree species have higher calorific value over some indigenous tree species. The differences in the study findings may be attributed to the differences of the methodological approaches used by the studies.

Comparatively in others studies in the region, in Tanzania, specifically Morogoro, carried out by (Magembe & Makonda, 2016), to determine the volume contribution of preferred tree species in burning bricks, where they documented that *Burkea africana* (4,078 m^3), *Azadirachta indica* (1,212 m^3) and *Mangifera indica* (872 m^3) together made up 8,027 m^3 of the total volume of the tree species consumed as fuelwood in brick making. The study in Morogoro showed that indigenous tree species were heavily sort after with *Burkea africana* being the most used, an indication that regionally we might be facing same problem regarding usage of both fruit trees and indigenous tree species as this study also showed great usage of *Mangifera indica* and some other indigenous tree species.

Much as these Miombo woodlands are being threatened because of over exploitation, they are quite vital to rural and urban livelihoods. This was also observed by Syampungani, *et al.*, (2009), who writes that 100 million people were directly or indirectly dependent upon Miombo woodland for their daily needs. Miombo woodlands affect the livelihoods of local communities through the provision of products such as medicines, energy, food, fibers, and construction and craft materials. The rural communities, for instance, consume a variety of edible fruits, which are normally gathered and eaten within the locality, while some are sold in the local markets

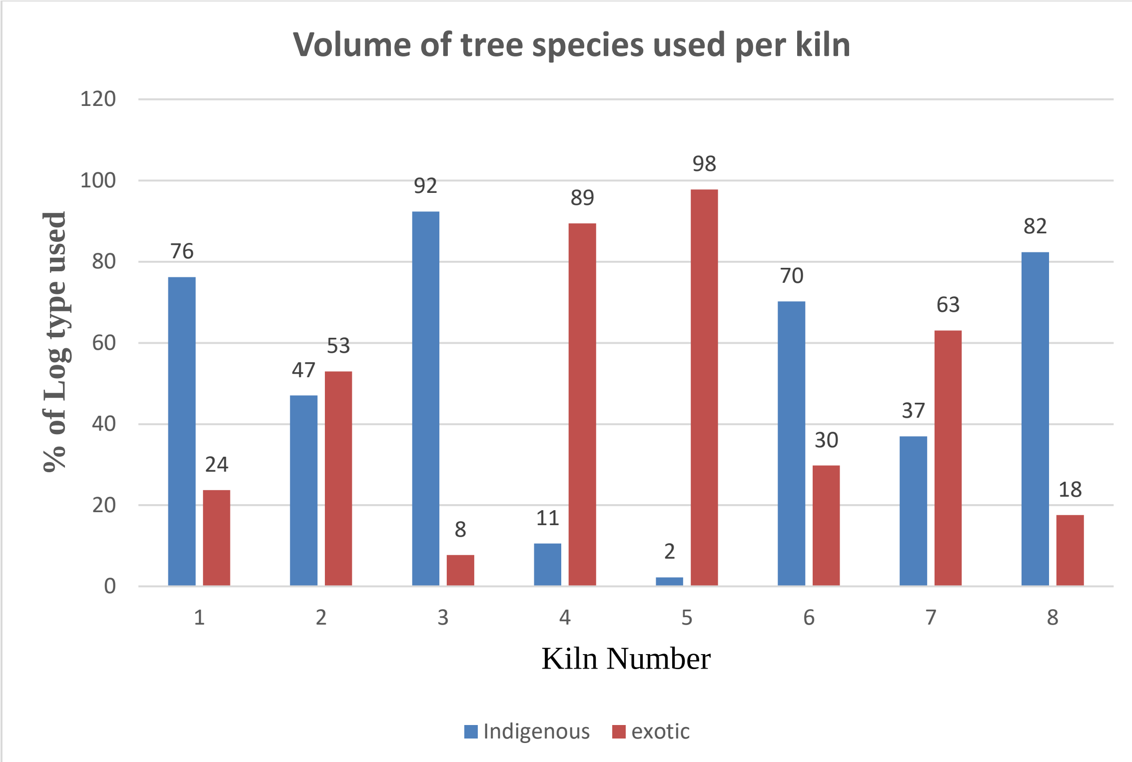

Figure 4.2 *: Different tree species used for burning bricks per kiln*

There was variation of dominance of exotic or indigenous use per kiln where some Kilns had more indigenous tree species and others more exotic tree species. With reference to Figure 4.2, Kiln 2, 4, 5 and 7 had more exotic tree species while Kiln 1, 3, 6 and 8 had more indigenous tree species. It was found that in some kilns the variation was so big, regarding the usage of exotic and indigenous tree species, for instance kiln 5 shows 98% was exotic and 2% indigenous where dominant species were *Mangifera indica* , *Casimiroa edulis* and *Persea americana*. These fruits are important to local populace in times of need, yet they were being used in burning the bricks. With this dominant use of these fruit trees, it means they are equally threatened if brick burning continues as an enterprise in this area.

In some societies, it is a taboo to cut fruit trees with their practical significance (Matose, 1992). As such it is a sad development where such vital trees are being used with neglect and nobody seems to worry and care for the plight of poor peasant farmers

Habitat destruction (specifically habitat fragmentation) is a direct impact of forest clearance in the community. This may become a major cause of species extinction worldwide if nothing is done to thwart the same (Laurance, 2010; Burgess *et al*., 2007). It is important to know that they are equally fast growing exotic tree species like Eucalyptus which do not have much productive and ecological service to the environment and these can be used in such enterprises (FAO, 2009).

4.6 Land degradation and livelihood threat due to brick burning in the study area

Importantly, the study found that water resources have been significantly degraded due to increased siltation in rivers and reservoirs due to brick making. Figure 4.2 (A) shows degradation of water reservoir in Songani due to brick making, while (B) shows gully erosion emanating from brick making .The once fertile land has been hardened and made unproductive with reference to agricultural use. The illustration (C) and (D) shows cutting of mango tree and the banana farm being swallowed in a deep gully emanating from brick making.

These people need to be empowered and civic educated so that they are able to make informed decisions which can help them halt degrading their land. Figure 4.3 shows some of the negative effects of the aftermaths of brick production activities in the study area.

Figure 4.3 : Some effects of brick production in Songani area: (A) degradation of water reservoir (B) Unproductive bare land after brick making (C) Clearance of fruit trees for burning bricks (D) threatening the existence of banana

4.7 Implication Regarding fuel wood consumption per species

The study showed that indigenous tree species are still more sort after. In this, some miombo endangered species are still being targeted like *Pterocarpus angolensis (Mlombwa) Julbernardia globiflora*, *Brachystegia bussei*, *Combretum zeyheri and Terminalia sericea.* The study also showed *Mangifera indica* was the most used with a total of 8.73m^3 wood volume. This may be an important indicator that accessibility to indigenous species is becoming more difficult and people are opting to using trees within their vicinity. Indigenous fruit tree species were also used like *Uapaka kirkiana*, a very important indigenous fruit tree, both ecologically and economically to most poor people.

4.8 Estimation of Contribution of brick making to deforestation in Malawi using the generated data

Table 4.8 : Estimated number of standard bricks per kiln to total wood volume used

Kiln	**Total Wood volume used/kiln (m^3)**	**Total Soil Volume (m^3)**	Volume of one standard brick (m^3)	Estimated Number of standard bricks per Kiln
1	4.53214331	49.3819125	0.0013225	37340
2	2.505555157	75.27819	0.0013225	56921
3	1.666130989	66.24666	0.0013225	50092
4	1.344285993	22.464	0.0013225	16986
5	5.930045161	177.615485	0.0013225	134303
6	1.123374975	18.835049	0.0013225	14242
7	1.57E+00	39.14586	0.0013225	29600
8	1.471453063	32.97125	0.0013225	24931
TOTAL	**20.14298865**	**481.9384065**		**364415**

The study revealed that **20.14 m^3** of wood volume was used to burn 481.94m^3 of total soil, which was equivalent to **364415** standard bricks (481.94/0.0013225m^3). This implied that a single brick required 5.53 x $10^{-5}m^3$ of wood volume to burn (20.14m^3 wood volume/364415bricks). The Malawi Urban Housing Sector Profile 2010 reveals that with the current rate of urbanization 21,000 housing units are required annually to meet the urban housing needs over the next 10 years. It is estimated that 20,000 burnt bricks can build a low cost house; 85000 bricks for a middle income house; while a high income house will require an estimated 150,000 to 300,000 including bricks for fencing around the house.

Having in mind that an average brick needs 5.53 x $10^{-5}m^3$ of wood volume to be burnt, therefore, a medium house of 85000 bricks will require $4.7x10^0m^3$ of wood volume to be burnt. Implying a total of **98,666 m^3** wood volume to burn 21000 houses/year as per demand according to Malawi Urban Housing Sector Profile 2010. In Malawi, miombo woodlands constitute 92.4% of the country's total forest area (Government of Malawi, 2010). Average volume of timber per hectare of mature woodland is $95m^3$. As such estimating hectarage usage of Miombo woodland, it will be **98,666** $m^3/95m^3$ which is equivalent of **1039** hectares of forest degradation (nationally).Degradation of such hectares of forests annually should be source of concern as forests are very important to many people in Malawi, as source of livelihoods, contribute to moderation of climatic patterns and help control soil erosion as they enhance infiltration of water among others.

4.9 Alternatives to Burnt Bricks in Malawi

Referring to the multiple disadvantages emanating from burning bricks, it could be very beneficial if Malawi could resolve to alternative methods of brick production. There are a number of cured brick products on the market like Hollow Brocks (HB) Interlocking Blocks (IB) and Compressed Stabilized Earth Brick (CSEB). Among these products the most viable option for many people in the villages and urban peripherals can be CSEB.

The production of CSEB requires moderate to low skilled worker since the CSEB manufacturing process is relatively simple. As such most people can easily be trained on and cost of machinery, especially the manual one is reasonable. For the CSEB to be made, it only takes 3 stages process which are: soil preparation, mix compression and the curing. However, it only need proper care in soil preparation, as correct selection of the soil help get the best result and after the mix is put in the mold, it should be given proper compressive load. Curing method in CSEB production use natural humid where bricks should be stacked immediately after compression and it is important to prevent rapid drying out of CSEB (Rahman *et a*l., 2011).

Importantly CSEB demonstrate many advantages compared to conventional fired brick like soil in its natural condition lack the strength, dimensional stability and durability required for building construction. On the other hand CSEB are ultimately greener, eco-friendly, and relatively durable than burnt brick. Also to help reduce deforestation in the area, use of alternative energy sources in brick making such as rice husks and bagasse can be employed. In addition, other recommendations are the establishment of woodlots, practicing agro-forestry systems and intensive afforestation and reforestation programs for more sustainable fuel wood use. Practicing intensive afforestation and establishment of woodlots may help where adoption of CSEB is proving problematic.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

In terms of percentage wood volume usage, the study showed that *Mangifera indica* an exotic fruit tree was the most used at 43.5%, followed by *Acacia polyacantha* at 17.1% an indigenous non-fruit tree species. The other tree species percentage wood volume usage was small.

A Pearson correlation coefficient of *(r^2)* = 0.023 was determined after correlating wood volume and soil volume in the study. In terms of Calorific Values (CV) the study determined that *Pterocarpus rotundifolius* (Sond) Druce, an indigenous non-fruit tree species, had the highest CV of 53,705,934.735 J/Kg. For exotic tree species, the tree species with highest CV was *Albizia glaberrima* (Schumach & Thonn) with a CV value of 49,392,106.82 J/Kg.

The tree with the lowest CV of all species was *Newtonia buchananii (Baker)* an indigenous non–fruit tree species which had 43,576,691.89 J/Kg.

5.2 Recommendations

From the results of the study, the following recommendations are put forward:

The study determined that *Pterocarpus rotundifolius* (Sond) Druce had a wood volume percentage use of 0.12%. This is lower, compared to usage of *Mangifera indica* and *Acacia polyacantha*, yet it was a tree with the highest calorific value. In this regard, stakeholders using wood for fuel, must know this differential aspect of calorific value in tree species. This is vital, as it will help activities requiring usage of wood for fuel target species with higher calorific value both indigenous and exotic. Also, most interventions aimed at reafforestation in most deforested areas should target species with higher calorific value, so that deliberately more of these tree species are regenerated.

The study also determined that some exotic tree species have higher calorific value than some indigenous tree species. This is important to note in the sense that, there is a common belief that almost all indigenous tree species have higher calorific value than exotic tree species. This in some cases has made it possible that indigenous tree species should be more targeted compared to exotic tree species. It is important, therefore, that communities need to be made aware that not all indigenous tree species have higher calorific value than exotic tree species. As such, the communities need to know the indigenous and exotic tree species which have higher calorific value for possible propagation and use.

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APPENDICES

APPENDIX 1: DATA COLLECTION TOOL TO QUANTIFY FUEL WOOD USE IN BRICK KILNS

Quantification of fuelwood and estimation of carbon content in round wood biomass used in brick burning in Zomba: Data collection tool/sheet

District:_____________ **Location:** _______________ **Kiln Number:**_____________ **Data Collectors**_______________________________________

Date: _________

Kiln Information

GPS coordinates:(Easting:_________________ **Northing**______________ **Altitude** _______________

Kiln Size : length_________________(m) Height _____________(m) Width _________________(m)

Tree Log Parameter								
Log ID	Woodtype		species	Mid-diameter (cm)	Length/ Height(m)	Additives used if any	What other methods do you use in burning bricks?	What practices/strategies have you put in place to ensure sustainable use of fuelwood rersources (trees
	Plantation	Indigenous						
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								

APPENDIX 2: LOG TYPE AND VOLUME USED PER KILN

LOG VOLUME USED/KILN/SPECIES								
KILN	SPECIES		LOG TYPE	TOTAL VOLUME/SPECIES (m3)	MEAN VOLUME/SPECIES (m3)	% of log volume used/species/kiln	% of Log Volume used/Log type	
							Indigenous	exotict
	Acacia polyacantha (	*non-fruit*	indigenous	3.455	2.29E-02	76.23324691		
1	*Persea americana(pe*	*fruits*	exotic	7.10E-01	2.22E-02	15.66764225	76.23256217	23.76668005
	Mangifera indica(Mo	*fruits*	exotic	3.67E-01	1.53E-02	8.099037803		
	Mangifera indica(Mango)	*fruits*	exotic	9.66E-01	3.72E-02	38.57268907		
	Julbernardia globiflo	*non-fruit*	indigenous	2.99E-01	1.50E-02	11.94026798		
	Brachystegia boehmi	*non-fruit*	indigenous	5.71E-01	4.39E-02	22.78696593		
	Newtonia buchanani	*non-fruit*	indigenous	2.65E-01	5.30E-02	10.57250723		
2	*Terminalia Sericea (N*	*non-fruit*	indigenous	2.60E-02	2.60E-02	1.038332759	47.03001635	52.96961819
	Lannea discolor(Chiu	*non-fruit*	indigenous	1.73E-02	8.67E-03	0.69194246		
	Toona celiata (Send	*non-fruit*	exotic	8.91E-02	2.97E-02	3.555379723		
	Albizia glaberrima (M	*non-fruit*	exotic	2.18E-01	3.11E-02	8.698671008		
	Eucalyptus camaldul	*non-fruit*	exotic	5.37E-02	1.79E+00	2.14287839		
	Mangifera indica(Mo	*fruits*	exotic	1.30E-01	2.59E-02	7.779100256		
	Julbernardia globiflo	*non-fruit*	indigenous	7.49E-03	7.49E-03	0.449610508		
	Brachystegia boehmi	*non-fruit*	indigenous	1.11E-02	3.71E-03	0.668794955		
	Lannea discolor(Chiu	*non-fruit*	indigenous	8.91E-02	1.11E-02	5.345017925		
	Diplorhynchus condy	*non-fruit*	indigenous	8.68E-02	7.89E-03	5.208894174		
	Uapaca kirkiana (M	*fruits*	indigenous	6.91E-01	8.03E-03	41.4661275		
	Pterocarpus angolen	*non-fruit*	indigenous	1.03E-01	8.61E-03	6.204194071		
	Brachystegia bussei (	*non-fruit*	indigenous	4.57E-02	5.08E-03	2.741801234		
	Vitex payos (Mpysipy	*fruits*	indigenous	7.26E-02	7.26E-03	4.358420826		
	Diospyros kirkii (Mch	*fruits*	indigenous	9.50E-02	8.63E-03	5.699791952		
3	*Uapaca nitida (Katso*	*fruits*	indigenous	2.47E-03	8.24E-03	0.148445711	90.88782997	10.24571304
	Philenoptera bussei (	*non-fruit*	indigenous	1.67E-02	5.55E-03	1.001601922		
	Senna petersiana (N	*non-fruit*	indigenous	2.37E-02	7.91E-03	1.423657573		
	Pterocarpus rotundif	*non-fruit*	indigenous	2.42E-02	6.06E-03	1.454267412		
	Parinari curatellifolia	*fruits*	indigenous	1.23E-01	8.17E-03	7.355364065		
	Pericopsis angolensis	*non-fruit*	indigenous	5.61E-03	5.61E-03	0.336942296		
	Annona senegalensis	*non-fruit*	indigenous	3.32E-02	6.63E-03	1.991079947		
	Combretum zeyheri (	*non-fruit*	indigenous	1.05E-02	5.23E-03	0.627501683		
	Faurea saligna (Chise	*non-fruit*	indigenous	1.61E-02	1.61E-02	0.967991119		
	Kirkia acuminata (Mt	*non-fruit*	indigenous	5.73E-02	5.73E-02	3.438325101		
	Senna spectabilis (Ke	*non-fruit*	exotic	4.11E-02	2.05E-02	2.466612786		
	Mangifera indica(Mo	*fruits*	exotic	7.04E-01	8.80E-03	52.37278405		
	Terminalia Sericea (N	*non-fruit*	indigenous	8.85E-02	2.95E-02	6.586693641		
4	*Toona celiata (Send*	*non-fruit*	exotic	7.47E-02	3.93E-02	5.556183759	10.5895621	89.41036406
	Diplorhynchus condy	*non-fruit*	indigenous	2.74E-02	9.14E-03	2.039223807		
	Acacia galpinii (Nkun	*fruits*	indigenous	2.64E-02	2.64E-02	1.963644652		
	Gmelina arborea (Mo	*non-fruit*	exotic	4.23E-01	2.49E-02	31.48139624		
	Persea americana(pe	*fruits*	exotic	3.46E-01	2.88E-02	5.827105707		
	Mangifera indica(Mo	*fruits*	exotic	5.31E+00	1.46E-02	89.4967889		
5	*Pterocarpus angolen*	*non-fruit*	indigenous	8.56E-02	7.14E-03	1.444204853	2.247689459	97.75186937
	Casimiroa edulis (Mo	*fruits*	exotic	1.44E-01	1.44E-02	2.427974764		
	Cordia abyssinica (M	*non-fruit*	indigenous	4.76E-02	1.57E-01	0.803484606		
6	*Mangifera indica(Mo*	*fruits*	exotic	3.35E-01	1.59E-02	29.80304952	70.19506397	29.80423687
	Khaya anthotheca (N	*non-fruit*	indigenous	7.89E-01	1.31E-02	70.19650766		
	Uapaca kirkiana(Mo	*fruits*	indigenous	2.28E-01	7.37E-03	14.54287313		
	Lannea discolor(Chiu	*non-fruit*	indigenous	3.31E-02	4.73E-03	2.108843949		
	Diplorhynchus condy	*non-fruit*	indigenous	3.21E-02	8.03E-03	2.043897668		
	Terminalia Sericea(N	*non-fruit*	indigenous	1.18E-03	1.18E-03	0.075006587		
7	*Julbernardia globiflo*	*non-fruit*	indigenous	3.34E-01	1.24E-02	21.25398884	40.84917325	59.15014383
	Brachystegia bussei (	*non-fruit*	indigenous	1.30E-02	4.32E-03	0.824563078		
	Persea americana(pe	*fruits*	exotic	1.12E-01	2.80E-02	7.124989068		
	Mangifera indica(Mo	*fruits*	exotic	7.69E-01	1.67E-02	48.97713665		
	Toona celiata (Send	*non-fruit*	exotic	4.79E-02	4.79E-02	3.048018111		
	Julbernardia globiflo	*non-fruit*	indigenous	1.01E+00	1.77E-02	68.36779409		
	Uapaca kirkiana(Mo	*fruits*	indigenous	1.93E-01	7.44E-03	13.14347055		
8	*Brachystegia bussei (*	*non-fruit*	indigenous	1.30E-02	4.32E-03	0.880082439	82.39134708	17.58126077
	Persea americana(pe	*fruits*	exotic	5.91E-02	5.37E-03	4.016438002		
	Mangifera indica(Mo	*fruits*	exotic	2.00E-01	8.68E-03	13.56482276		

APPENDIX 3: INVENTORY OF TREE SPECIES USED IN BURNING BRICKS IN THE STUDY AREA

INDIGENOUS TREE SPECIES USED		
GENUS &SPECIES	**COMMON NAMES**	**LOCAL NAME**
Julbernardia globiflora (Benth.) Troupin	Munondo	Mchenga
Brachystegia boehmii	Prince of Wales' feathers	Mombo
Lannea discolor (Sond.) Engl.	Live-long	Chiumbu
Diplorhynchus condylocarpon Oliv	Horn-pod tree	Thombozi
Pterocarpus angolensis DC	Bleedwood tree	Mlombwa
Brachystegia bussei Harms	large-leaved brachystegia	Mtwana
Philenoptera bussei (Harms) Schrire.	Narrow lance-pod	Chimpakasa
Senna petersiana (Bolle) Lock.	Monkey Pod	Ntowa
Pterocarpus rotundifolius (Sond) Druce.	Round-leaved bloodwood	Matakale
Pterocarpus angolensis DC.	Bleedwood tree	Muwanga
Combretum zeyheri Sond.	Large-fruited bushwillow	Kadale
Faurea saligna Harv.	Beechwood	Chisese
Kirkia acuminata Oliv.	white seringa	Mtumbu
Acacia polyacantha Wild	Cutch tree	Nthethe
Newtonia buchananii (Baker) G.C.C. Gilbert & Boutique	Forest newtonia	Mkweranyani
Terminalia Sericea Burch. ex DC.	Silver cluster-leaf	Naphini
Albizia glaberrima (Schumach. & Thonn.) Benth	Lowveld albizia	Mtangatanga
Acacia galpinii Burtt Davy.	Monkey-thorn	Nkunkhu
Cordia abyssinica R. Br. ex A. Rich.	Large-leaved saucer-berry	Msingati

INDIGENOUS FRUIT TREES		
GENUS &SPECIES	**COMMON NAMES**	**LOCAL NAME**
Uapaca kirkiana Müll.Arg	Mahobohobo	Masuku
Vitex payos (Lour)Merr.	Chocolate berry	Mpysipysa
Diospyros kirkii Hiern.	Large-leaved jackal-berry	Mchenje
Uapaca nitida Müll. Arg	Narrow-leaved mahobohobo	Katsokolowe
Parinari curatellifolia Planch. ex Benth.	Hissing tree	Maula
Annona senegalensis Pers.	wild custard-apple	Mpoza
EXOTIC TREES		
GENUS &SPECIES	**COMMON NAMES**	**LOCAL NAME**
Khaya anthotheca (Welw.) C.DC.	Red mahogany	M'bawa
Gmelina arborea Roxb.	Gmelina, White teak	Malaina
Eucalyptus camaldulensis	Bluegum	Bulugamu
Toona celiata M.Roem.	Red cedar, Indian m	Sendeleya
Senna spectabilis (DC.) H. S. Irwin and R. C. Barneby.	Spectacular cassia	Kesha wa Maluwa
EXOTIC FRUIT TREES		
GENUS &SPECIES	**COMMON NAMES**	**LOCAL NAME**
Mangifera indica L.	Mango	Mango
Persea americana Mill	Avocado	Peyala
Casimiroa edulis Llave & Lex.	White sapote	Masuku a chizungu

APPENDIX 4: CALORIFIC VALUE FOR SPECIES

CALORIFIC VALUE FOR TREE SPECIES							
NAME	**COMMON NAME**	**LOCAL NAME**			Mean Calorific Value (CV) (J/Kg)	**group mean**	**group sd**
Casimiroa edulis Llave & Lex	White sapote	Masuku a chizungu	fruits	exotic	45,908,689.55		
Mangifera indica	Mango	Mango	fruits	exotic	47,679,204.53		
Persea americana Mill	Avocado	peyala	fruits	exotic	47,699,400.81	47,095,764.96	1,028,087.06
Albizia glaberrima (Schumach & Thonn) Benth	Lowveld albizia	Mtangatanga	non-fruit	exotic	49,392,106.82		
Eucalyptus camaldulensis	Bluegum	Bulugamu	non-fruit	exotic	48,790,911.94		
Gmelina arborea Roxb.	Gmelina, White teak	Malaina	non-fruit	exotic	47,856,968.32		
Senna spectabilis	Spectacular cassia	Kesha wa Maluwa	non-fruit	exotic	45,690,225.98		
Toona celiata M.Roem	Red cedar, Indian	Sendeleya	non-fruit	exotic	45,137,746.72	47,373,591.95	1,880,796.09
Acacia galpinii Burtt Davy	Monkey-thorn	Nkunkhu	fruits	indigenous	45,523,950.67		
Diospyros kirkii	Large-leaved jackal-berry	Mchenje	fruits	indigenous	47,858,796.37		
Parinari curatellifolia Planch. Ex Benth	Hissing tree	Maula	fruits	indigenous	48,703,433.18		
Uapaca kirkiana Mull.Arg	Mahobohobo	Masuku	fruits	indigenous	48,294,155.85		
Uapaca nitida Mull.Arg	Narrow-leaved mahobohobo	Katsokolowe	fruits	indigenous	49,165,646.57		
Vitex payos (Lour)Merr	Chocolate berry	Mpysipysa	fruits	indigenous	44,273,597.17		
Annona senegalensis Pers	Wild custard-apple	Mpoza	fruits	indigenous	46,913,564.15	47,247,591.99	1,788,595.02
Acacia polyacantha Wild	Cutch tree	Nthethe	non-fruit	indigenous	48,089,359.92		
Brachystegia boehmii	Prince of wales' feathers	Mombo	non-fruit	indigenous	47,068,995.77		
Brachystegia bussei Harms	Large-leaved rachystegia	Mtwana	non-fruit	indigenous	47,987,826.90		
Combretum zeyheri Sond	Large-fruited bushwillow	Kadale	non-fruit	indigenous	46,179,418.17		
Cordia abyssinica	Large-leaved saucerberry	Msingati	non-fruit	indigenous	47,930,969.52		
Diplorhynchus condylocarpon	Horn-pod tree	Thombozi	non-fruit	indigenous	46,946,468.11		
Faurea saligna Harv.	Beechwood	Chisese	non-fruit	indigenous	48,239,881.87		
Julbernardia globiflora	Mchenga	Mchenga	non-fruit	indigenous	47,001,222.03		
Khaya anthotheca (Welw.) C.DC	Red mahogany	M'bawa	non-fruit	indigenous	46,783,276.52		
Kirkia acuminata Oliv.	white seringa	Mtumbu	non-fruit	indigenous	47,561,561.57		
Lannea discolor	Live-long	Chiumbu	non-fruit	indigenous	47,230,146.25		
Newtonia buchananii (Baker) G.C.C. Gilbert & Boutique	Forest newtonia	Mkweranyani	non-fruit	indigenous	43,576,691.89		
Pericopsis angolensis	Bleedwood tree	Mlombwa	non-fruit	indigenous	46,808,473.74		
Philenoptera bussei (Harms) Schrire	Narrow lance-pod	Chimpakasa	non-fruit	indigenous	47,365,668.12		
Pterocarpus angolensis DC.	Bleedwood tree	Muwanga	non-fruit	indigenous	49,990,916.38		
Pterocarpus rotundifolius (Sond) Druce	Round-leaved bloodwood	Matakale	non-fruit	indigenous	53,705,934.74		
Senna petersiana (Bolle)	Monky Pod	Ntowa	non-fruit	indigenous	48,321,070.16		
Terminalia Sericea Brush. Ex DC.	Silver cluster-leaf	Naphini	non-fruit	indigenous	47,046,278.79	47,657,453.36	1,961,906.68