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Households' woodfuel consumption and deforestation in Morogoro and Songea Districts, Tanzania

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ABSTRACT

There paucity of empirical evidence of deforestation attributable to household wood fuel consumption hampers effective strategy to reduce wood consumption and mitigate climate change impacts. The objectives of the study were to: (i) obtain households' characteristics, (ii) determine quantity of charcoal consumption, (iii) determine quantity of firewood consumption, (iv) estimate deforestation due to charcoal consumption; (v) estimate deforestation due to firewood consumption, and (vi) estimate environmental cost of deforestation. Data were collected using household questionnaire survey, focus group discussion, key informant interview, direct measurements of household fuels and researcher's direct observation. Data were analysed using *SPSS* and *Excel* statistical computer programmes. The findings reveal that charcoal consumption is estimated at 3.50±0.26kg/household/day (256±18/capita/year) and firewood consumption at 7.30±0.46 kg/household/day (533±33kg/capita/year). Deforestation attributable to charcoal consumption was 1.20–4.80 ($\times 10^{-4}$) ha/household/day [0.88–3.49 ($\times 10^{-2}$) ha/capita/year]. Deforestation attributable to firewood consumption was 6.85–33.07 ($\times 10^{-6}$) ha/household/day [5.01–24.12 ($\times 10^{-4}$) ha/capita/year]. The net deforestation was 3.37-21.59 ha/household/day. Findings suggested that woodfuel contribute 49% of total deforestation. and cost of deforestation was US$ 6,252,012. The study recommends that woodfuel production and consumption technologies need improvements.

Keywords: Deforestation – household – charcoal – firewood - environmental cost

INTRODUCTION

An overview of deforestation

Tropical deforestation is a widespread environmental problem and continues to escalate at a very alarming rate (Wibowo and Byron 1999) with deleterious consequences including: greenhouse gas emission, especially CO_2 (Sanz 2007, Urquhart *et al.* n.d, Olander *et al.* 2008, Fearnside 2005, House *et al*. 2002, Hughes *et al.* 2000, Angelsen 1995), biodiversity loss (Olander *et al.* 2008, Fearnside 2005, Toham and Teugels 1999, Angelsen 1995), soil erosion and consequent soil infertility (Ehui and Hertel 1992, Angelsen1995), increase in surface albedo and consequent climate variability (Henderson-Sellers and Gornitz 1984, Zhang *et al.* 1996), reduction in precipitation , evaporation rate and consequently hampers hydrological systems (Fearnside 2005, Kanae *et al.* 2001, Henderson-Sellers *et al.* 2002, Gaertner *et al.* 2001, Munishi *et al.* 2009), increase in global surface temperature (Mayer *et al.* 1993), and spread of malaria disease (e.g. Vittor *et al.* 2006, Kanzaria n.d , Guerra *et al.* 2006, Pattanayak *et al.* 2003, Bødker *et al.* 2000). There is a growing concern over shrinking area of tropical forests (Scrieciu 2007) at the global level, the ratio of planted to cut down forest is 1 to 6 hectares, while for Africa, this ratio dramatically decreases to 1 to 32 hectares (Scrieciu 2007). Policy makers, scientists and the public are increasingly concerned about tropical deforestation and its negative consequences such as climate change, biodiversity loss, reduced timber supply, flooding, siltation and soil degradation (Kaimowitz and Angelsen 1998).

Deforestation in the tropics accounts for up to 20% of global emissions of CO_2, making it the second most important contributor to climate change after the combustion of fossil fuel and the largest source of greenhouse gas (GHG) emissions in developing world (Ebeling and Yasue 2008, Contreras-Hermosilla, 2000, Betts *et al.* 2008). Deforestation results in annual degradation of 12 million ha of fertile land and loss of thousands of species (estimates range between 8,000 and 28,000 per year). Bellassen and Gitz (2008) report that deforestation is leading 14,000 to 40,000 plant species to extinction.Other authors have indicated that deforestation and forest degradation are active contributors to global warming, carbon emission and anthropogenic emission of greenhouse gases (Betts *et al*. 2008, Murdiyarso and Skutch 2006,Van Oosterzee and Garnett 2008, Bellassen and Gitz 2008, Sasaki and Putz 2008).

On a similar note, Ehui and Hertel (1992) argue that when tropical forests are cleared, the physical and chemical properties of soil undergo significant changes leading to nutrient loss, accelerated soil erosion and declining agricultural yields. Sahani and Behera (2001) further assert that deforestation reduces soil organic carbon, total nitrogen, microbial biomass carbon and nitrogen; and impairs microbial respiratory quotient (q CO_2). Vågen *et al.* (2005) assert that soil organic carbon content decreases by 0 to 63% following deforestation. According to Guerra *et al.* (2006) canonical epidemiological understanding is that deforestation *increases* malaria risks in Africa and the Americas, and *diminishes* it in South-east Asia. Pattanayak *et al.* (2003) elaborates further: "each environmental change, whether occurring as a natural phenomenon or through anthropogenic activities, changes the ecological balance and context within which disease host or vector and parasite breed, develop and transmit diseases". In particular, deforestation: (a) changes the ecology of the disease vector and its options for hosts. It makes the area more sunlit and more neutral pH which can favour specific anopheline larvae development; (b) deforestation can change local climate thereby affecting the spread of diseases by reducing the moisture held by vegetation and raising ground temperature – higher temperatures increase the rate at which mosquitoes develop into adult; the frequency of their blood feedings; the rate at which parasites are acquired; and the incubation of the parasites within the mosquitoes; (c) deforestation is often the beginning of a variety of land-use change; (d) deforestation is accompanied by migration that may enhance the spread of malaria; (e) ecosystem change such as deforestation has several putative climatic impacts via role of trees in the carbon cycle and regional weather patterns; and (f) ecosystem change such as deforestation can play a role in antibiotic resistance that has become a major concern for several *Plasmodium* species.

Yasuoka and Levins (2007) report that deforestation and land transformation influence anopheline vectors, especially larval survivorship, adult survivorship, reproduction and vectorial capacity, through changing environment and microclimatic conditions such as temperature (average, variability), sunlight (amount, duration), humidity and water condition (distribution, temperature, quality, turbidity), soil condition and vegetation. In Kenya, deforestation enhances mosquito reproductive fitness – increasing mosquito population growth potential (Afrane *et al.* 2006). According to Koenraadt *et al.* (2006) global warming and effects of *el niño* may increase larval vector survival and may lead to malaria epidemics. Malaria causes globally, about 1 million deaths annually, out of which > 90% occurs in Africa. The disease is a number-one killer of children, pregnant women and the elderly on the continent. Kanzaria (n.d.) reports that the most prevalent parasite (agent) in highlands of East Africa is *Plasmodia falciparum* while the most prevalent vector (mosquito) is *Anopheles gambiae*. Both *agent* and *vector* are temperature dependent: higher temperature means more proliferation. Besides, the vector breeds in sunlit pools of standing water.

In Tanzania, malaria causes between 70,000 and 125,000 deaths annually and accounts for 19% of the total health expenditure (Yanda *et al.* 2006). It is recommended (Pattanayak *et al.* 2006) to strategically link research and policy at the *malaria--deforestation–poverty* nexus in a comprehensive decision-analysis framework that channels research to the most pressing policy issues. Savigny *et al.* (2004) report that the whole Tanzanian population is at risk of malaria, noting that malaria in the country is believed to be directly or indirectly responsible for about 16 million annual malaria episodes and 100,000 to 125,000 annual deaths; and Tanzania spends approximately US$ 2.14 per person per annum on malaria services (Jowett *et al.* 2000). Experience from Tanzania indicates that malaria exposure during pregnancy has a delayed effect on birth weight, but a more acute effect on still birth risk (Wort *et al.* 2006). According to URT (2005), malaria is the single most important cause of morbidity and mortality in Tanzania, both among adults and children under five years of age, costing the nation 3.5% of the gross domestic product (GDP).

Tropical deforestation is considered to be a global problem due to its widespread occurrence and its ecological, social and cultural significance (O'Brien, 2000). Deforestation is a potential threat to ecological sustainability and socio-economic development in the long-term (Mertens and Lambin 1997). Chomitz and Gray (1996) posit that the loss of tropical forests is a global concern because of its impacts on biodiversity and climate. Deforestation is a complex socio-economic, cultural and political event – it is thus incorrect to attribute forest decline to a simple cause–effect relationships or assume that a relationship will remain unaltered over time (Geist and Lambin 2001, Kaimowitz and Angelsen 1998, Contreras-Hermosilla 2000). These are the primary actors in the forest decline and their immediate motivations are the *direct causes* of deforestation and forest degradation. Hassan and Hertzler (1988) posit that one important cause of deforestation in arid and semi-arid countries is the overcutting of undervalued trees for fuelwood. It is estimated that the extraction of wood from tropical forest for timber, charcoal burning and fuelwood constitutes 68% of the proximate causes of deforestation in Africa, 89% in Asia and 51% in Latin America (Geist and Lambin 2001). A study carried out by Geist and Lambin (2002) reveals that fuel wood consumption has the highest contributory effect on deforestation. Charcoal consumption is a real threat to the long-term persistence of forests in Tanzania (Mwampamba 2007). Geist and Lambin (2001, 2002) have revealed that one of the direct causes of deforestation is wood extraction for firewood and charcoal. Many authors have strongly pointed out that woodfuel consumption is one of the key causes of deforestation (Malimbwi *et al.* 2001, Misana 1999, Butler 2006, Dodo 2007).

Kulindwa and Shechambo (1995) attempts to quantify the relative importance of factors contributing to deforestation in Tanzania and suggested that fuelwood extraction accounts for the highest percentage of deforestation (55.4%). The authors did not however explain *how* the estimates were arrived, and as such, the provided estimates are, to put it mildly, questionable.

FAO (1993) defines deforestation as change of land cover with depletion of tree crown cover to less than 10 percent. FAO (2001) defines deforestation as the conversion of forest to another land use or the longer-term reduction of the tree cover canopy below the minimum 10% threshold. UNFCCC (2006) defines deforestation as a ‘measurable sustained decrease in crown cover’ below a 10-30% threshold. Kaimowitz and Angelsen (1998) define deforestation as: complete long-term removal of tree cover. Forest degradation is even more vaguely defined and consequently more difficult to measure than deforestation. This study has adopted a definition of deforestation from Kaale (2005): deforestation is a progressive removal of trees from a wooded land without requisite regeneration.

The difficulties in estimating deforestation rates notwithstanding, several attempts have been made to determine the rate of deforestation in Tanzania: Luoga *et al.* (2002) asserted that before independence (in 1961), the forest cover was 50% of total land area in the country. In the late 1970s, it decreased to 45%; in the mid-1990s it further decreased to 41% and in the late 1990s it was just 36% of total land area. Kaale (2005) attributes such changes to hitherto increasing human population: in 1967 Tanzania had a population of 12.3 million people with annual national wood fuel consumption of 24.6 million m^3 and per-capita consumption of 2.0 m^3 year^{-1}. In 2002, population was 34.6 million people with annual national wood fuel consumption of 44.8 million m^3 and 2003 per-capita wood fuel consumption of 1.0-1.5 m^3 capita^{-1}year^{-1}. The report by URT (1998) estimates the deforestation rate in Tanzania at a rate of 130,000-500,000 ha year^{-1}. FAO (2000) estimates a deforestation rate in Tanzania at 0.2%. Other deforestation rate estimates are FAO (2001) : 92,000 ha year^{-1} or 0.2%, mainly due to illicit logging (Butler 2006) ; Mariki *et al.,* (2003) : 91,000-98,000 ha year^{-1}; Kilahama (2005) : 250,000-300,000 ha year^{-1}; Kaale (2005) : > 400,000 ha year^{-1} due to charcoal production alone and 20,000 ha year^{-1} due to tobacco curing; Butler (2006) : 412,200 ha year^{-1} or 1.1% (between 2000-2005); Monela and Abdallah (2007) : 91,2000 ha year^{-1}; and UN (2007): 412,000 ha year^{-1} or 1.0% between 1990-2000 and 412,000 ha year^{-1} or 1.1% between 2000-2005. According to NAFORMA (2015), annual deforestation is 372,871 ha. Research on deforestation may render more effective solutions if conducted at a more disaggregated, local level (Scrieciu 2007). Kaimowitz and Angelsen (1998) posit that research on deforestation will probably be more productive if it concentrates on *household-* and *regional-level* studies instead of national and global studies.

Determinants of household energy consumption

A vast literature has highlighted factors which affect patterns and levels of household energy consumption. The factors include: age of the household head (Erlandsen and Nymoen 2008, Lenzen 2006), income, fuel price, price of related appliances, opportunity cost for firewood collection (UNDP/World Bank 2003, Adelekan and Jerome 2006, Lenzen 2006), level of urbanisation, availability of fuel and related appliances, cultural preferences (Adelekan and Jerome 2006), household size (Hartmann and Sherbinin 2001, Lenzen 2006), house type, tenure type, employment status, geographical location, number of children, and car ownership (Lenzen 2006). Fuchs and Lorek (2000) classified the determinants of direct energy consumption by households into six categories: economic factors (disposable income, consumer prices, spending pattern, availability of credit), socio-demographic factors (household size and structure, age, behavioural factors, lifestyle, attitudes), living situation (per-capita floor space, dwelling type, house age, standard of insulation), *technology* (energy efficiency of household appliance), supplier (efficiency, energy content of energy carrier) and climatic factors. According to Piet and Boonekamp (2007), choices made by households are not only affected by income and energy prices, but also by others factors: composition of households, owned versus rented dwellings, and energy use standards for new dwellings or appliances. Jiang (2007) asserted that the main drivers of energy use and carbon emissions are demography (population size; composition – age and gender; distribution – spatial, rural/urban), economic growth, technology, policy and lifestyle. Abrahamse (2007) categorised salient determinants of energy consumption into two groups: societal factors (technological developments, economic growth, demographic factors, institutional factors and cultural factors) and individual-level factors (awareness, beliefs, values, attitudes and knowledge).

It is evident from the above introduction that deforestation as an environmental problem is real and that the effects of wood fuel on deforestation are not properly understood. It is for the above-mentioned reasons that this study was conducted to address six objectives namely: (i) characterise the households in the study area; (ii) quantify charcoal consumption in the study area, (iii) quantify firewood consumption in the study area (iv) estimate deforestation due to charcoal consumption; (v) estimate deforestation due to firewood consumption, and (v) estimate environmental cost (both perceived and empirical) of deforestation in the study area.

METHODOLOGY

This study was conducted with households around and within the eastern and southern miombo woodlands in Tanzania: *Morogoro* and *Songea* districts in *Morogoro* and *Ruvuma* regions respectively (Fig.1). Each district was sub-divided into three strata: rural, peri-urban and urban areas; and sample households were drawn from each stratum.

In ***Morogoro Region***, the annual rainfall ranges from 600 mm in lowlands to 1200 mm on the highland plateau. However, there are areas which experience exceptional droughts (with less than 600 mm of rainfall). The mean annual temperatures vary with altitude from the valley bottom to the mountain top: *between 18^{o}C on the mountains to 30^{o}C in river valleys*. In most parts of the region, the average temperatures are almost uniform at 25^{o}C. The economy of the region is dominated by agriculture (80-90 percent of the region's labour force) and allied activities. The major activities include:(i) small scale farming; (ii) cattle production; (iii) plantations and estates (sisal, sugar); (iv) traditional fishing; and (v) some mining activities.

In ***Ruvuma Region***, rainfall starts in December and ends in April. Total average annual rainfall is over 1,200 mm and the amount varies between districts. For instance, Mbinga District has an annual average rainfall of 1,800 mm while Tunduru District receives an average rainfall of 918 mm. The cold period is between June and August with temperatures of approximately 11°C while the average annual temperature is approximately 22°C. The relative humidity ranges between 90% in March and 37% in October. The Ruvuma region is mainly agrarian where 87% of its population reside in rural areas and are actively engaged in land-based production. The major economic activities of the region are agricultural farming, livestock rearing, lumbering, fishing, bee keeping, mining and trading.

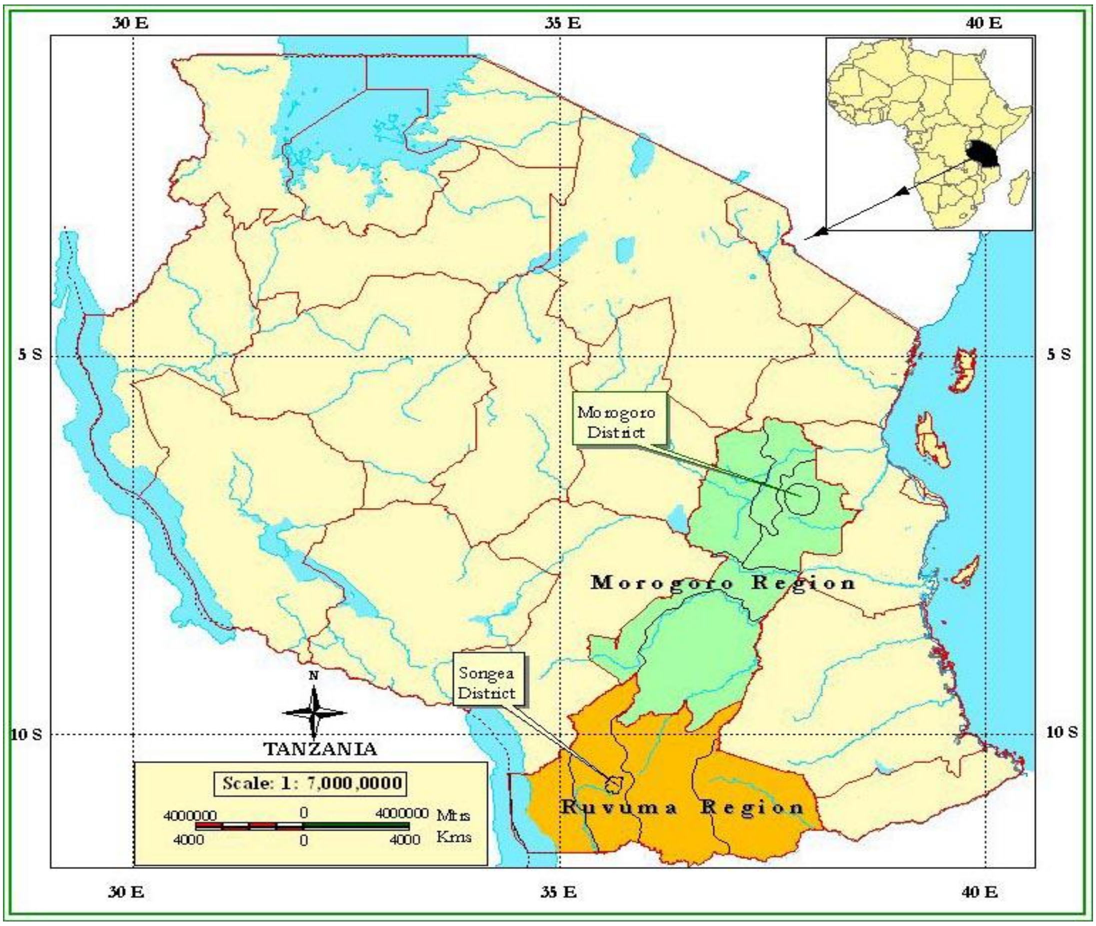

Figure 1: Map of Tanzania showing the study sites

Sampling procedure, sample size and data collection

The design of the study was a descriptive and analytic cross-sectional survey. The target populations for this study were households in Morogoro and Songea districts. The sampling frame was in three types depending on the sampling phase: (i) sampling of villages and Wards, (ii) sampling of hamlets and streets, and (iii) sampling of households. During sampling of villages in rural areas and wards in peri-urban and urban areas, the sampling frame was the list of villages bordering the selected forests and list of wards in the municipalities respectively. During sampling of hamlets in rural areas and streets in peri-urban and urban areas, the sampling frame was the updated list of all hamlets in the selected villages and list of all streets in the selected wards respectively. When sampling households for the study, the sampling frames that were used are the updated lists of household registers in the sampled hamlets and streets. The list was updated by removing households which are no longer existed and adding the new existing and missed households Stratified random sampling design was used in the present study. Stratification was carried out at two levels: (a) stratification of study sites in the study districts into rural, peri-urban and urban areas, and (b) stratification of respondents into wealth categories: low, medium and high. Rural areas in the context of the present study refer to communities bordering the forests. Urban areas refer to the community residing fairly in the centre of municipality. Peri-urban areas refer to the areas geographically located within the municipality, but lying on its periphery.

A total of 568 respondent households were involved in this study (**Table 1**). The sample size for the study was computed using equestions 1, 2 and 3 as recommended by Bartlett *et al.* (2001):

$$n = \left(\frac{n_0}{1 + \frac{n_0}{N}} \right) \qquad (1)$$

The computation of sample size for *categorical* data, according to Bartlett *et al.* (2001), follows the same way as in *continuous* data, except in the computation of n_0, which is:

$$n_0 = \left(\frac{t^2 \times pq}{d^2} \right) \qquad (2)$$

Where: p is the proportion of respondent that will give you information of interest (the proportion *confirming*), q viz (1-p) is the proportion not giving you information of interest (proportion *defective*), and $p*q$ is the estimate of variance (*which is maximum when p = 0.50 and q=0.50)*. The maximum population variance of 0.25 will give the maximum sample size. Consequently, the formula used to determine sample size (n) from a population (N) is:

$$n = \frac{384}{1 + \frac{384}{N}} \qquad (3)$$

Data were collected using a number of techniques: household questionnaire survey, focus group discussion, key informant interview, direct measurements of household fuels and researcher's direct observation. **Household questionnaire survey:** Questionnaire construction began by first defining the *domain of information* in order to obtain the required information. This was achieved through an extensive and rigorous search of pertinent literature. I tried as much as possible, to make the questionnaire: *brief* (keeping questions short, and asking one question at a time); *objective* (paying attention to neutrality of the words); *simple* (using language which is simple in words and phrase); *specific* (asking precise questions); and *informative* (covering all necessary information needed). All three types of question formats were used: *multiple choice* (closed ended) questions, *numeric open-ended* questions, and *text open-ended* questions. Attention was also given to issues such as *opening* questions, question *flow*, and location of *sensitive* questions.

Table 1: Sampled households in the study sites

District	Stratum	Sampled village/ward	Sampled hamlet/street	Households in sampled hamlet/street	Sampled households	Sub-total for stratum
Morogoro	Rural	Fulwe	Dindili	39	35	167
			Ulundo	68	58	
		Maseyu	Kitulangalo	45	41	
			Ng'ambala	36	33	
	Peri-urban	Kingoluwira	Mahakamani	86	70	115
			Tambuka reli	51	45	
	Urban	Kihonda	Kilombero	104	82	82
Songea	Rural	Mtyangimbole	Kanisani	45	40	91
		Ndilimalitembo	Ndilimalitembo	59	51	
	Peri-urban	Mshangano	Mshangano	74	62	62
	Urban	Songea mjini	CCM	59	51	51
GRAND TOTAL					**568**	**568**

Focus group discussion: During questionnaire pilot-testing, a focus group discussion (FGD) approach was used to elicit contextual information on various environmental and energy-related issues and to establish criteria to be used for households' stratification. This was carried out in the ward headquarters. The focus group (in each ward head quarter) comprised of 6 (six) members: the Ward

Executive Officer (WEO), two members from the Ward Environmental Management Committee, two primary school teachers who have stayed in the area for the longest period, and a famous wood fuel vendor. The checklist for the FGD comprised five questions and the process was estimated to last for not more than two hours. The questions were: (i) How do households in this area meet their energy needs? (ii) What are general energy-related problems the households face?, (iii) What do you consider the best ways to address the above-mentioned problems?, (iv) What are the environmental problems facing your community?, and (v) I want all households in this area stratified into three main wealth categories (life standard): low, medium and high wealth categories. What are the household attributes you would use to allocate the households in their respective categories?

Key informant interview: The key informants in the present study were: district forest officers, wood fuels vendors, famous and influential elders, and charcoal stoves vendors. The District Forest Officers provided the information on the existing forests (number and categories) in their districts upon which the researcher based his sampling of forests to be studied. Also provided was general information on the management aspects of the forests, main threats to the existing forests, and steps they take to address the management problems of the forest resources. They also provided the information on the bottlenecks to the successful discharge of their responsibilities, and registered their opinions on how to better improve forest resources in their respective districts. Interview of famous and influential elders was conducted in rural and peri-urban areas. The choice of famous and influential elders as key informants was based on the assumption that such people know their areas properly and extensively. They are also well conversant with various socio-cultural aspects (which may influence energy consumption patterns). They provided information on the changes of wood resources over time (deforestation) and reasons behind these changes, households' asymmetrical preference for miombo woodlands as their energy sources, and what should be done to address energy problems in general and destruction of forest resources in particular.

The vendors of wood fuel (firewood and charcoal) provided valuable information on prices, supply and demand aspects of the fuels and on what they considered as problems facing their businesses. The information sought from these people also shed light on changes of wood fuel availability over time and preference of consumers between charcoal and firewood. Retailers and wholesalers (*where available*) of charcoal stoves were interviewed on aspects regarding prices, availability of customers and quality of stoves they are selling (as perceived by their customers). They also provided information regarding the customers' preference on specific type of charcoal stoves, with possible explanations; and pointed out the sources of stoves (whether local or external to the area).

Direct measurements of household fuels: The direct measurements were conducted to quantify the fuels consumed by the households. The fuels involved in direct measurement were firewood and charcoal. The procedure was that the sampled households were visited one morning before commencing their cooking activities. Measurements were taken for the available fuels and recorded in the measurement sheet. The same households were re-visited the following day (at the same time as the previous day) and measurement of the remaining fuels were then taken and recorded. The difference in measurements, i.e., Measurement (1st day) minus the Measurement (2nd day) was taken as the household daily fuel consumption intensity. The instrument used for fuel measurement (firewood and charcoal) was a spring balance.

Data analysis

Characterising the respondent households in the study area

Descriptive statistical analysis was carried out to summarise, organise and simplify a set of scores (Gravetter and Wallnau 2004, 2007). The central tendency (average or representative score) for numeric data (interval or ratio) was determined by mean. The central tendency determination for discrete variables was a mode. The measure of variability within the numeric (interval or ratio) data was standard deviation. The categorical variables were summarised using bar charts and pie charts; whereas numerical variables were summarised using histograms. Re-coding was also applied to "open-ended" questions' responses before carrying out *multiple responses analysis*. Manipulations of data into suitable forms for analysis were carried our primarily by *Excel Computer Programme*. Household income categories were collapsed from previous eight categories to three categories.

Charcoal and firewood consumption intensities

Both descriptive and inferential statistics were carried out to analyse intensities of woodfuel in the study area. The measure of central tendency was a mean. According to Gravetter and Wallnau (2004), inferential statistics use the limited information from samples to answer general questions about the population. The present study made use of various inferential statistical analyses: standard error of the mean (SEM) is the standard deviation of the sampling distribution. It shows how likely it is that a particular sample comes from that population. It is the discrepancy between sample statistic (M) and population parameter (µ). Interval estimations using the 95% confidence interval were made to sample means when generalising to the target population.

Charcoal consumption and deforestation

Determination of deforestation caused by charcoal consumption requires knowledge of a number of variables including; consumption levels of charcoal (kg/capita/year); charcoal kiln efficiency (K_e) (see formula 4)); stock density of forest (tonnes/hectare); proportion (percentage) of total charcoal production that comes from the natural forests; percentage of charcoal produced from trees cut deliberately for charcoal production differentiated from charcoal produced using trees from farm clearings.

$$K_e = \left(\frac{Amount\ of\ charcoal\ produced\,[kg]}{Amount\ of\ wood\ used\ to\ produce\ charcoal\,[kg]} \right) \times 100\% \quad (4)$$

For the purpose of this study, the adopted values are: kiln efficiencies range from 11% to 30% (Malimbwi *et al.* 2001); about 93% of the stem (and not 100%) is harvested for charcoal production (Chidumayo 1991); the forest stock densities range from 58 tonnes/hectare to 73 tonnes/hectare [Adapted from Malimbwi 2000 and CARE Tanzania, 2002 (in Kaale 2005)]; nearly 90% of charcoal is produced from natural forests (Kaale 2005); approximately 84% of charcoal production in natural forests involves cutting of trees deliberately for that purpose (Malimbwi *et al*. 2001). Because *only 93% of the wood stem* is used for charcoal, the amount of wood used to produce charcoal should be multiplied by a factor of 1.075 to get the total wood cut for charcoal production. Consequently, the deforestation due to charcoal consumption is given by the following equation:

$$D = \left[1.075 \times 10^{-3} \times 0.90 \times 0.84 \times \left(charcoal \times \frac{1}{K_e} \times \frac{1}{S} \right) \right] \quad (5)$$

Where: D is Deforestation (ha); *charcoal* is charcoal consumption intensity; K_e = Kiln efficiency (in proportions); S is stock density (tonnes of wood ha^{-1} of forest); $1.075 \times 10^{-3} \times 0.90 \times 0.84$ is a constant that incorporates: (1) the fact that only 93% of the wood stem is used for charcoal production, (2) the unit conversion of 1000 kg of wood into 1 tonne of wood, (3) the fact that 90% of charcoal comes from natural forests, and (4) the fact that 84% of charcoal produced from natural forests involves deliberate tree cutting for charcoal production (16% of charcoal is produced from trees in farm clearing). Table 2 shows eight different scenarios considered when translating charcoal consumption into hectares of forest. The scenarios are kiln efficiency-stock density-consumption levels scenarios. It implies that deforestation due to charcoal consumption is dependent on three above-named variables (kiln efficiency, stock density, consumption levels) each of which has its minimum and its maximum values. Consequently, eight variables are L_kL_sA, L_kH_sA, H_kL_sA, H_kH_sA, L_kL_sB, L_kH_sB, H_kL_sB, and H_kH_sB. The symbols used here have the following meanings: L= Low forest stock intensity; H= High forest stock intensity. When forest stock intensity is combined with two kiln efficiency scenarios (i.e L_k =Low efficiency and H_k = High efficiency) then it generates 4 Kiln efficiency-forest stock (K-S) scenarios. When K-S scenarios are combined with consumption intensities scenarios (A = Minimum, and B= Maximum) then a total of eight scenarios are generated as presented in Table 2.

Table 2: Summary of scenario used in computing deforestation due to charcoal consumption

(a)		(b)			(c)		
							K-S-C scenarios*
							L_kL_sA
							L_kH_sA
					Levels of consumption		H_kL_sA
				K-S scenario	Min (A)	Max (B)	H_kH_sA
		Stock density (t ha^{-1})		1(L_kL_s)	1A	1B	L_kL_sB
		Low (58)	High (73)	2(L_kH_s)	2A	2B	L_kH_sB
Kiln efficiency (%)	Low (11)	L_kL_s	L_kH_s	3(H_kL_s)	3A	3B	H_kL_sB
	High (30)	H_kL_s	H_kH_s	4(H_kH_s)	4A	4B	H_kH_sB

* K-S-C scenarios means: Kiln efficiency-Stock density-Consumption levels scenarios. ***Source:*** Adapted from Mwampamba (2007)

Firewood consumption and Deforestation

Translating firewood consumption into deforestation in natural forests is relatively more complex and challenging due to a number of reasons:

(i) The present study suggests that 73.6% of households collect firewood from natural forests, 1.4 percent of households collect firewood from plantation forests, 19.5% collect firewood from own farms, while 5.5 percent collect firewood from other places;

(ii) Canonical understanding of firewood collection process is that not all firewood is cut from standing trees: Bratkovich *et al.* (2004) assert that 70% of household firewood is collected from dead trees and harvested residues, 12% from standing live trees growing on the forest land, and 18% from other sources. Driscoll *et al.* (2000) establishes that 76% of households collect dead fallen trees, 6 percent collect firewood from standing live trees, and 18% collect firewood from standing dead trees. Whitney (1987) asserts that in rural areas, most firewood comes from dead wood, and that only 10% of firewood involves the destruction of standing live trees. World Bank Industry and Energy Department (1991) estimates that in many rural areas, dead wood may represent 80% of the firewood collected by the villagers. Anthropological and ecological study by Abbot and Homewood (1999) found that women carry bundles of firewood composed of both dead and live wood whose proportions are not known, noting further that 39% of women collect firewood by hand, 36% collect firewood by machetes, 13% collect firewood by axes suitable for felling trees, and 12% of women collect firewood using stick to dislodge the branches still attached to the trees.

This study makes a number of assumptions in order to paint a picture on deforestation caused by firewood consumption: *Assumption 1*: all households have access to all sources of firewood in the study area; *Assumption 2:* about 74% of households' firewood comes from natural forests; *Assumption 3*: of the firewood collected from natural forests, about 6-20% involves cutting the standing live trees; *Assumption 4:* according to Leach and Mearns (1988), firewood consumption uses only 60% of the total tree. In light of the above assumptions, deforestation due to firewood consumption can be computed as follows:

$$D = \left[1.667\times0.74\times\left(\frac{1}{1000}\times Firewood \times \%Green\,wood\right)\right]\times\frac{1}{S} \qquad (6)$$

Where: *D* is deforestation; *Firewood* is amount of firewood consumption; S is stock density (tonnes wood ha^{-1} of forest); $1.667\times0.74\times10^{-3}$ is constant that incorporates: (1) the fact that only 60% of the wood stem is used for firewood consumption, (2) the fact that 74% of households' firewood comes from natural forests, and (3) the unit conversion of 1000kg of wood into 1 tonne of wood. The range of stocking density was subjectively but optimistically extended to 74 tonnes/ha. Table 3 shows the scenarios used in computing deforestation due to firewood consumption. There are eight different scenarios considered when translating firewood consumption into hectares of forest. The scenarios are percent of wood obtained from live trees -stock density-consumption levels scenarios. It implies that deforestation due to firewood consumption is dependent on three above-named variables (percent of wood obtained from live trees, forest stock density, consumption levels) each of which has its minimum and its maximum values. Consequently, eight variables are L_tL_sA, L_kH_sA, H_tL_sA, H_tH_sA, L_kL_sB, L_kH_sB, H_kL_sB, and H_tH_sB. The symbols used here have the following meanings: L_s= Low forest stock intensity; H_s= High forest stock intensity. When forest stock intensity is combined with two scenarios regarding percent of wood obtained from live trees (%) (i.e., L_k =Low percentage and H_k = High percentage) then it generates four percent of wood obtained from live trees-forest stock (K-S) scenarios. When K-S scenarios are combined with consumption intensities scenarios (A = Minimum, and B= Maximum) then a total of eight scenarios are generated as presented in Table 3.

Costs of deforestation

Several methods exist for estimating costs of REDD (Reduced emissions from deforestation and degradation) and include opportunity costs, implementation costs, transaction costs institutional costs, conversion to per-tone of carbon, and co-benefits (Wertz-Kanounnikoff 2008, Stefano and Benoit (2009). According to Ickowitz *et al.* (2017) the cost of deforestation is between 96.87-904.54 USD/ha. Rai *et al.* (2017) reported that the annual cost of reducing deforestation in Nepal is between USD 654/ha and USD 3,663/ha. The study conducted recently in Indonesia by Li *et al.* (2020) revealed that the cost of deforestation is 5,466.90-11,049.60 USD/ha. According to URT (2000), at a global level, the value of the Tanzanian forests is estimated at US$ 1,500 per ha based on value of recycling and fixing of carbon dioxide. This was the method used in this study to estimate cost of deforestation (in monetary term) attributable to woodfuel consumption.

According, the cost was computed as follows:

Cost (USD) = Deforestation (ha) × Cost of deforestation (USD/ha) (7)

Table 3: Summary of scenario used in computing deforestation due to firewood consumption

(a)		(b)			(c)		
							T-S-C scenarios*
							L_tL_sA
							L_tH_sA
					Levels of consumption		H_tL_sA
				T-S scenario	Min (A)	Max (B)	H_tH_sA
		Stock density (t ha^{-1})		1(L_tL_s)	1A	1B	L_tL_sB
		Low (58)	High (74)	2(L_tH_s)	2A	2B	L_tH_sB
Percent of wood obtained	Low (6)	L_tL_s	L_tH_s	3(H_tL_s)	3A	3B	H_tL_sB
from live trees (%)	High (20)	H_tL_s	H_tH_s	4(H_tH_s)	4A	4B	H_tH_sB

* T-S-C scenarios means: Percent of trees from live standing trees-Stock Density-Consumption levels scenarios

RESULTS

Characteristics of respondents in the study area

The findings reveal that 568 respondents took part in the household survey. It was further revealed that both *household heads* and those who are *not* household heads participated in answering survey questionnaires. It is also evident from the findings that the study sample comprised of both *male-headed* households and *female-headed* households, *albeit* the former constitutes the majority. Female-headed households can further be categorised into two groups: those who are married and those who are not. The study attained a *fairly good gender balance*: the number of *male respondents* was comparable to that of *female respondents*. The income distribution among respondents revealed that38.9%, 26.2% and 34.9% were in low-income category, medium income category and high-income category respectively. Prior to actual data collection, the respondents were stratified into three wealth categories (based on the criteria developed during pilot study, using focus group discussion): low wealth categories, medium wealth categories, and high wealth categories. Figure 3 indicates that the respondents constituted a fairly good representation across the three wealth category strata. During data collection, household assets were used as proxy for household wealth. Both animate (cattle, goats, sheep, pigs and chickens) and inanimate assets (land, motor cars, bicycles, hand hoes, sickles, machetes, and sprayers) were recorded for each respondent household and converted into monetary value to reflect the wealth status of a respective household**.** The results suggest that there is fairly even household wealth (household assets) ownership. It was revealed that 54% of respondents were heads of households. Approximately 82.4% of respondents were male-headed households and 85.2% owned their dwellings. Figure2 indicates that majority of respondents were in medium wealth categories.

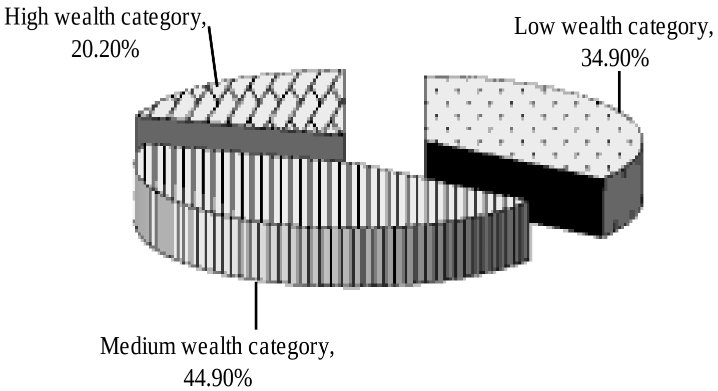

Figure 2: Wealth categories of respondents as defined during FGD

Charcoal and firewood consumption rates and deforestation

The charcoal and firewood consumption intensities in the study area are presented in Table 4 and Table 5 respectively. It can be revealed that charcoal consumption is highest in urban area (3.64±0.0.18 kg/household/day) and lowest rural areas (3.20±0.30 kg/household/day). On the other hands, firewood consumption is highest in rural areas (7.60±0.32 kg/household/day) and is lowest in urban area (4.20±0.54 kg/household/day). Table 6 presents results of confidence interval, and reporting with 95% confidence, overall, 79.8% - 83.2% of households in the study area use firewood as energy source at a rate of 7.16 - 7.44 kg household^{-1} day^{-1}, while 56.4% - 59.6% of households in the study area use charcoal as energy source at a rate of 3.44 – 3.56 kg household^{-1} day^{-1}.

Table 4: Charcoal consumption intensity in the study area (Mean ± s.e)

Stratum	Morogoro District		Songea District		Pooled sample	
	(kg/hh/day)	(kg/capita/yr)	(kg/hh/day)	(kg/capita/yr)	(kg/hh/day)	(kg/capita/yr)
Rural	2.80±0.26	204±18	4.8±0.92	350±66	3.20±0.30	234±22
Peri-urban	3.12±0.30	285±29	3.73±0.67	274±47	3.30±0.27	241±18
Urban	2.90±0.17	175±11	4.62±0.30	281±47	3.64±0.0.18	219±11
Overall	3.00±0.14	219±11	4.50±0.26	329±18	3.50±0.26	256±18

Table 5: Firewood consumption intensities in the study area (Mean ± s.e)

Stratum	Morogoro District		Songea District		Pooled sample	
	(kg/hh/day)	(kg/capita/yr)	(kg/hh/day)	(kg/capita/yr)	(kg/hh/day)	(kg/capita/yr)
Rural	9.90±0.38	431±29	9.80±0.43	715±29	7.60±0.32	555±22
Peri-urban	5.52±0.42	504±40	10.22±0.55	745±40	7.50±0.40	548±29
Urban	3.50±0.30	212±18	7.20±2.00	438±91	4.20±0.54	256±33
Overall	5.50±0.25	402±18	9.90±0.34	715±26	7.30±0.46	533±33

Table 6: Confidence interval for wood fuel consumption intensities

	N	n	$\left(\frac{n}{N}\right)$	*FPCF*	Sample statistic Average consumption (kg/hh/day)		Inferential statistic (95% C.I) Average consumption (kg/hh/day)	
					Firewood	Charcoal	Firewood	Charcoal
1. Morogoro District								
1.1 Rural	189	167	0.88	0.342	9.90 (SD = 4.0)	2.80 (SD = 1.4)	9.69–10.11	2.73–2.87
1.2 Peri-urban	137	115	0.84	0.402	5.52 (SD = 3.5)	3.12 (SD = 1.9)	5.26–5.78	2.98–3.26
1.3 Urban	104	82	0.79	0.462	3.50 (SD = 1.6)	2.90 (SD = 1.4)	3.34–3.66	2.76–3.04
1.4 Overall (Morogoro)	430	364	0.85	0.392	5.50 (SD = 3.7)	3.00 (SD = 1.5)	5.35–5.65	2.94–3.06
2. Songea District								
2.1 Rural	104	91	0.87	0.355	9.80 (SD = 4.0)	4.80 (SD = 2.5)	9.51–10.09	4.62–4.98
2.2 Peri-urban	74	62	0.84	0.405	10.22 (SD = 4.1)	3.73 (SD = 2.2)	9.81–10.63	3.51–3.95
2.3 Urban	59	51	0.86	0.371	7.20 (SD = 5.3)	4.62 (SD = 2.0)	6.66–7.74	4.42–4.82
2.4 Overall (Songea)	237	204	0.86	0.374	9.90 (SD = 4.1)	4.50 (SD = 2.1)	9.69–10.11	4.39–4.61
3. Pooled sample								
3.1 Rural	293	258	0.88	0.346	7.60 (SD = 4.4)	3.20 (SD = 1.9)	7.41–7.79	3.12–3.28
3.2 Peri-urban	211	177	0.84	0.402	7.50 (SD = 4.4)	3.30 (SD = 2.0)	7.24–7.76	3.18–3.42
3.3 Urban	163	133	0.82	0.430	4.20 (SD = 3.1)	3.64 (SD = 1.8)	3.97–4.43	3.51–3.77
3.4 Overall	667	568	0.85	0.386	7.30 (SD = 4.5)	3.50 (SD = 1.9)	7.16–7.44	3.44–3.56

Deforestation due to charcoal and firewood consumption

The deforestation rates due to charcoal consumption are shown in Table 7, while the deforestation rates due to firewood consumption are shown in Table 8. It is apparent that charcoal consumption causes deforestation at a rate of 1.20–4.80 $(\times 10^{-4})$ ha/household/day while firewood consumption causes deforestation at a rate of 6.85–33.07 ($\times 10^{-6}$) ha/household/day). It is also evident that deforestation due to firewood consumption is highest in rural areas while deforestation due to charcoal consumption is highest in urban areas.

Table 7: Deforestation in the study area due to charcoal consumption (*possible range*)

Stratum	Morogoro District		Songea District		Pooled sample	
	(ha/hh/day) $(\times 10^{-4})$	(ha/capita/yr) $(\times 10^{-2})$	(ha/hh/day) $(\times 10^{-4})$	(ha/capita/yr) $(\times 10^{-2})$	(ha/hh/day) $(\times 10^{-4})$	(ha/capita/yr) $(\times 10^{-2})$
Rural	0.90–3.90	0.69–2.83	1.40–7.30	1.05–5.30	1.10–4.50	0.79–3.26
Peri-urban	1.00–4.40	0.95–4.00	1.10–5.60	0.84–4.09	1.12–4.55	0.83–3.30
Urban	1.00–3.90	0.61–2.37	1.60–6.30	0.87–4.18	1.28–4.87	0.77–2.93
Overall	1.10–4.00	0.77–2.93	1.60–6.10	1.15–4.42	1.20–4.80	0.88–3.49

Table 8: Deforestation in the study area due to firewood consumption (possible range)

Stratum	Morogoro District		Songea District		Pooled sample	
	(ha/hh/day) $(\times 10^{-6})$	*(ha/capita/yr)* $(\times 10^{-4})$	*(ha/hh/day)* $(\times 10^{-6})$	*(ha/capita/yr)* $(\times 10^{-4})$	*(ha/hh/day)* $(\times 10^{-6})$	*(ha/capita/yr)* $(\times 10^{-4})$
Rural	9.54–43.81	4.03–19.60	9.39–43.59	6.87–31.71	7.29–33.75	5.34–24.59
Peri-urban	5.11–25.31	4.65–23.18	9.69–45.90	7.06–33.45	7.11–33.66	5.20–24.59
Urban	3.21–16.19	1.94–9.80	5.21–39.20	3.48–22.54	3.67–20.20	2.24–12.32
Overall	5.26–24.50	3.85–17.90	9.58–43.64	6.90–31.58	6.85–33.07	5.01–24.12

Gross and net total deforestation due to wood fuel consumption

According to Luoga *et al.* (2004) the natural regeneration in miombo woodlands ranges between 59-74% of total deforested area. Based on this information, the *gross*- and *net-total daily households'* deforestation intensities were computed, and are respectively, presented in Table 9 and Table 10. It is shown in Table 10 that Range of net deforestation (ha/day) (Min-Max) is 3.37-21.59, and it is evident that net deforestation in Morogoro District is higher than that in Songea District.

Table 9: Gross daily deforestations in the study area

Source of deforestation	Daily deforestation (ha/household/day)		% of households in use of source	Total households	No. of households in use of source	Total daily deforestation (ha/day)	
	Lower limit	Upper limit				Lower limit	Upper limit
Pooled sample							
Firewood	0.00000685	0.00003307	81	172,546	139763	0.96	4.62
Charcoal	0.00012	0.00048	58	172,546	100077	12.01	48.04
Total (pooled)						12.97	52.66
Morogoro District							
Firewood	0.00000526	0.0000245	82	110,930	90963	0.48	2.23
Charcoal	0.00011	0.0004	64	110,930	70995	7.81	28.40
Total (Morogoro)						8.29	30.63
Songea District							
Firewood	0.00000958	0.00004364	80	61,616	49293	0.47	2.15
Charcoal	0.00016	0.00061	49	61,616	30192	4.83	18.42
Total (Songea)						5.30	20.57

Table 10: Net deforestation in the study area

District	Gross Deforestation (ha/day)	Natural regeneration in miombo woodlands (% of deforested land)*	Net deforestation (ha/day) [(100-NR)*GD]/100	Range of net deforestation (ha/day) (Min-Max)
Pooled sample	12.97	59	5.32	
	12.97	74	3.37	3.37-21.59
	52.66	59	21.59	
	52.66	74	13.69	
Morogoro	8.29	59	3.40	
	8.29	74	2.16	2.16-12.56
	30.63	59	12.56	
	30.63	74	7.96	

Songea	5.30	59	2.17	
	5.30	74	1.38	1.38-8.43
	20.57	59	8.43	
	20.57	74	5.35	

* Adapted from Luoga *et al.* (2004)

Total deforestation in the country attributable to woodfuel consumption

The deforestation due to woodfuel (countrywide) is deduced as follows:

$$Deforestation = \left(\frac{91.4\% \times Total\ hh_s\ in\ the\ country}{91.4\% \times Total\ hh_s\ in\ the\ study\ area}\right) \times 4555.2\ (ha\ year^{-1}) \quad (8)$$

$$= \left(\frac{6{,}996{,}036}{172{,}546}\right) \times 4555.2\ (ha\ year^{-1})$$

= 184, 694.77 ha year^{-1}.

Environmental costs of deforestation in the study area

The environmental costs of deforestation due to woodfuel are presented in Table11. It was revealed that the total environmental cost due to deforestation in the study area was USD **6,252,012, segregated as follows: costs due to firewood was USD** 580,788 and the cost due to charcoal was USD = 6,252,012. Besides the perceived costs by respondents relating to household woodfuel consumption is presented in Table 12.

Table 11: Environmental cost of deforestation due to household woodfuel

Environmental problem	Description				
Deforestation		Gross deforestation			Net deforestation (ha/day)
	Source	Range (ha/day)	Mid-point (ha/day)	% of total deforestation	
	Firewood	0.96 - 4.62	2.79	8.50	(8.5/100)$\times$12.48 = 1.0608
	Charcoal	12.01-48.04	30.025	91.50	(91.5/100) $\times$12.48=11.4192
	Total	**12.97-52.66**	**32.815**	**100**	**12.48**
Environmental Cost					
	Firewood	1.0608 $\times$365(days/year) $\times$1500(US$/ha) = 580,788			
	Charcoal	11.4192$\times$365(days/year) $\times$1500(US$/ha) = 6,252,012			
	Total	**6,252,012**			

Table 12: Households' perceived health problems in the study area

Biomass fuel's health problems			
Category label	*Code*	*Count*	*Percent of responses*
TB	1	90	12.7
Cancer	2	49	6.9
Coughing	3	108	15.2
Headache	4	74	10.4
Eye irritation	5	65	9.1
Injuries	6	51	7.2
Lung problems	7	24	3.4
Heart problems	8	6	0.8
Flu	9	27	3.8
No response	10	217	30.5
	Total responses	711	100
568 valid cases			

DISCUSSIONS

Forests provide an abundant, locally available, and environmentally renewable source of fuel. Nevertheless, their utilisation has to be sustainable on an ecological, economic and social basis to ensure that future generations can utilise the forest with the same intensity (Röser *et al.* 2008). The argument has been buttressed by Lunnan *et al.* (2008) who posit that forest bioenergy chains must be managed in a sustainable way, and the production, transport, combustion and distribution must be performed in line with principles of sustainable development. The results from the present study revealed that overall charcoal consumption in the study area was found to be 3.50±0.26 kg/household/day (equivalent to 256±18 kg/capita/year), while overall firewood consumption was 7.30±0.46 kg/household/day (equivalent to 533±33 kg/capita/year). The obtained results reveal the actual situation in Tanzania where majority of households have heavy dependency on woodfuel arguably due to lack /insufficient alternative sources of fuel or due the high costs of the would be alternative sources of fuel. These findings are comparable to those found by Wintkyaw *et al*. (2020) which indicated that the average per capita annual firewood consumption rate for cooking was 530 kg for households that used exclusively firewood for cooking. The findings from this study are however at variance with those by Shaheen *et al.* (2016) which revealed that fuel wood consumption per household was estimated in 16.2 Mg year^{-1}, and 5.9 kg day^{-1} *per capita* (ranging from 6.6 kg in summer to 3.9 kg in winter). Consumption at the higher and lower altitudinal villages was recorded as 18.3 and 10.7 Mg annually.

Empirical evidence from the present study suggests that wood fuel consumption in the study area is, overall, unsustainable: *it causes a net deforestation ranging between 3.37 and 21.59 ha/day* (in the study area with a total number of 172,546 households). The results from the present study indicate that 91.4% of the households in the study areas use wood fuel as the source of energy. This implies that, *assuming* a constant deforestation rate, 91.4% of 172,546 households cause an annual deforestation of: 365 days × [(3.37+ 21.59)/2] ha/day = 4555.2 ha/year. *Assuming further* that the household wood fuel consumption rate observed in the study area applies to the whole country, then, at the national level the deforestation due to household wood fuel consumption is:

The most recent statistics on deforestation rate in Tanzania is that provided by NAFORMA (2015): 372,871 ha/year. It can thus be reasonably inferred that the household wood fuel accounts for [(184,694.77 ha/year ÷ 372,871 ha/year) × 100%] = 49% of total deforestation in the country. This inference should nonetheless be made with caution for a number of reasons: deforestation rates reported by FAO (which have been used by the United Nations) are, according to Hoare (2007), *unreliable* and *misleading*: FAO's approach in determining deforestation, *vastly underestimates the impacts of human on forests*; computation of deforestation rate in *the present study* is not devoid of uncertainties: to compute deforestation attributable to household wood fuel consumption, several *intelligent* (guided) assumptions had to be made. This is the main source of uncertainties in the computed estimates. The uncertainty in the computations of deforestation attendant on household wood fuel consumption notwithstanding, the empirical evidence suggest that household wood fuel consumption is a significant contributor to deforestation in the country, and thus requires due attention. Woodfuel as a significant source of deforestation has also been asserted by a number of authors. Sedano *et al.* (2016) asserted that charcoal production for urban energy consumption is a main driver of forest degradation in sub Saharan Africa. Chidumayo and Gumbo (2012) have also reported that charcoal production in tropical regions of the world is often perceived to have devastating ecological and environmental effects. Further, a study by Adebayo *et al*. (2019) concluded that charcoal production one of the major causes of deforestation. According to the authors (ibid), their study on charcoal producers' perceived effect of charcoal production on deforestation revealed that majority (93.8%) of the respondents strongly agreed that charcoal production is one of the primary causes of deforestation.

According to URT (2000), at a global level, the value of the Tanzanian forests is estimated at US$ 1,500 per ha based on value of recycling and fixing of carbon dioxide. Therefore, total environmental cost attributable to deforestation due to household woodfuel consumption is estimated at US$ 6,252,012 (Table 11). Some other studies which have assessed environmental costs of deforestation include Thompson *et al.* (2013) who assessed the set-up, implementation, and monitoring costs, i.e., collectively the transaction costs, of six of the first seven REDD+ project designs from the Peruvian Amazon and compare them with established projects in Brazil and Bolivia. The estimated costs varied greatly among the assessed projects from US$0.16 to 1.44 ha^{-1} yr^{-1}, with an average of US$0.73 ha^{-1} yr^{-1}, though they are comparable to earlier published estimates.

According to Schmidt (2008), globally, the net present value of services from forests ecosystems that we lose each year is estimated at between US$ 1.35 trillion and US$3.1 trillion, for discount rates of respectively 4% and 1%. The Author (ibid) concluded that deforestation is costing the world US$ 2-5 trillion per year.

CONCLUSIONS AND RECOMMENDATIONS

Speaking with 95% confidence, each household in the study area use firewood and charcoal at consumption rate of 7.16 – 7.44 kg/day and 3.44–3.56kg/day respectively. It can be reasonably concluded further that although determining deforestation due to wood fuel consumption seems to be only an approximation (due to a number of assumptions associated with its computations), empirical evidence suggest that approximately 49% of deforestation in Tanzania is attributed to household wood fuel consumption. Furthermore, this study concludes that total annual environmental cost attributable to deforestation due to household woodfuel consumption is estimated at US$ 6,252,012. This study recommends that improved wood fuel consumption and production (charcoal) using efficient cook stoves and improved charcoal production technology would appreciably reduce deforestation and its attendant environmental costs.

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