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Firewood Utilisation and Its Implication on Trees around Mopipi Village in Boteti Sub-District of Botswana

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Authors' contributions

This work was carried out in collaboration between all authors. Authors WNM, LKA, JRA and RC designed the study. Authors WNM, LKA, KM, FVD and LM participated in field investigation, data collection and authors WNM, LKA, KM and FVD performed the statistical analysis. Authors RJS and JSP managed the literature searches and analyses of the study. Author WNM wrote the first draft of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

A household survey was done to assess the number of people using firewood in order to determine the amount of available firewood, its rate of utilisation and the distance travelled per selected household. There are a total of 383 households in Mopipi village with an average household size of eight (8) people. A sample size of seventy-nine (79) households were interviewed for the study on their use of fuelwood. Four transects of 14 km radiating from the Mopipi village were used to

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measure the biomass of both live and dead trees. Five sampling points at different distances along the transect were located. At each sampling point, three 50m x 10m quadrats were demarcated. Firewood biomass was determined by measuring the basal area at ankle height and adjusted by using regression curves formulae. Biomass of live trees was dominated by *Colophospermum mopane* woodlands, but its standing dead wood was only available at further distances. Most households gathered firewood by head-loads within a range of 4-6 km from the village. Trade-offs were clearly involved when people collected less preferred species at near distances. Consumption rate per household was estimated at 10 kg per day per household. Reasonable biomass of live trees occurred near the village, concurring with household claims that they do not chop live trees.

Keywords: Consumption rate; households; firewood; preferred species; woody biomass.

1. INTRODUCTION

Fuelwood continues to play a significant role as an energy source for many rural households in Africa and particularly in the rural areas of Botswana [1,2] where it is used across a very wide spectrum of activities including domestic cooking and house insulation [3,4,5,6,7]. In Botswana, firewood is the principal energy source used for cooking in 46% households, whereas, in rural areas, the number reaches up to 77% [1,2]. This represents a decline of about 90% since 1981 [8,9], but still significant enough to attract policy attention.

Firewood is used not only by households but also by other sectors such as education, health and manufacturing industries. Examples include schools, prisons and local community gatherings for cooking and provision for warm water. In Botswana, as in many other developing countries; the households sector is the main consumer of firewood [3,6,10,11]. Many rural households depend primarily on woody biomass for their daily energy needs [2,11]. As biomass production is generally not sustainable due to its high rate of utilisation, repeated collection of firewood is causing deforestation, thus hampering the ecosystem viability [12,13,7,14].

Firewood in Botswana accounts for a lower percentage (46%) of total energy consumption as compared to some other African countries such as Nigeria (80%), Uganda (92%), Rwanda (90%), Burundi, Malawi and Somalia (>90%) [15] and South Africa (54%) 16). In order to survive, however, rural households have to depend on many kinds of available fuel biomass and have to adopt several mechanisms for obtaining energy. Several authors have reported a positive change in the economic behaviour of households to adapt to firewood scarcity [16,6,10].

Despite the fact that firewood is the most important source of primary energy in Botswana, there exists a wide knowledge gap of firewood availability around settlements showing that little has been done to come up with firewood inventories in the country. Attempts to map quantities of woody biomass using satellite imagery [17,18,19] and 1:50,000 aerial photographs [20], have failed to provide the required level of details for planning purposes [21].

Preference of the woody biomass resource by communities as a source of firewood is a critical factor in the understanding of future rural energy demands [22,23,3]. In eastern Botswana the most preferred firewood species are *Combretum apiculatum* and *Combretum imberbe* which later got depleted, such that households had to switch to *Dichrostachys cinerea* and *Senegalia erubescens*, which are also getting scarce [24] with time. The distance travelled and time-taken to collect firewood are the two factors that have frequently been used in socio-economic studies as an index of scarcity. A field-work undertaken in Mochudi village shows that firewood was taken from a mean distance of 4.4 km, 20 km and 44 km, for head-loads, donkey-carts and small trucks, respectively [25]. Some trees are not used as firewood as they are associated with taboos, or spirits while others produce toxic and/or unpleasant smoke and unpleasant smells.

Firewood usage has been declining over the years while gas and electricity consumption has been on the rise [10]. This is mainly attributed to the rising level of affluence as well as the increased access to electricity. Reports showed that in Botswana, local energy resources are considered to be in abundance including coal (200 billion tonnes), sunshine (3200 hrs at 21 MJ/m2), biogas (2.5 million cattle, 3 kg dung/livestock unit/day) and firewood (200

tonnes/annum) [10]. Botswana's domestic energy-related resources present immense opportunities for addressing her energy insecurities and increasing access to energy services. The most significant input is the technology required to leverage the energy latent in these resources.

The use of firewood affects the biodiversity conservation and depletion is likely to occur because of harvesting at rates higher than those at which nature can replenish the wood resources. As with wildlife, the capacity of government to monitor wood resources is limited and without the management of firewood quotas being devolved to local communities and the requisite local capacity developed, it is the poor who stand to lose. Mopipi village was chosen for study because the area has received a significant decline in the density and amount of vegetation normally used for firewood over the past 4-5 decades [18] in the vicinity of the village.

1.1 Objectives of the Study

The main objective of this study was : (1) to determine the firewood inventory in order to evaluate the extent of firewood availability to the local community, and (2) to determine the impacts of firewood harvesting on land degradation.

1.2 Description of the Study Site

The study was carried out in Mopipi Village in the Boteti-sub District of Botswana (Fig. 1). The area has semi-arid climate with soil comprising mainly of arenosols which are conspicuously dissected by the semi-perennial Boteti river. Fluvisols form a narrow flood buffer zone along the river, providing almost year-round moisture, which allows residents to practice recessional farming [26].

These semi-arid soils are considered problematic because their physio-chemical properties limit the uses for agricultural purposes. They generally have low organic matter content and an unstable structure. The main problems associated with these soils are high levels of salinity and sodicity, poor drainage around pans, soil erosion and low soil fertility [27]. The saline soils, brackish groundwater and forage for cattle need certain mineral supplementation. The term semi-arid means that the rains are concentrated mostly in the summer season (October to April) with an average rainfall of 350 mm/yr. The rate of evapotranspiration for the area is 1860 mm per year. The temperature ranges between 25-30°C, but higher temperatures (up to 40°C) have also been recorded, especially in the summer months of drought years. Winter temperature ranges between 15-20°C during the day, but at night occasional frosts occur [27].

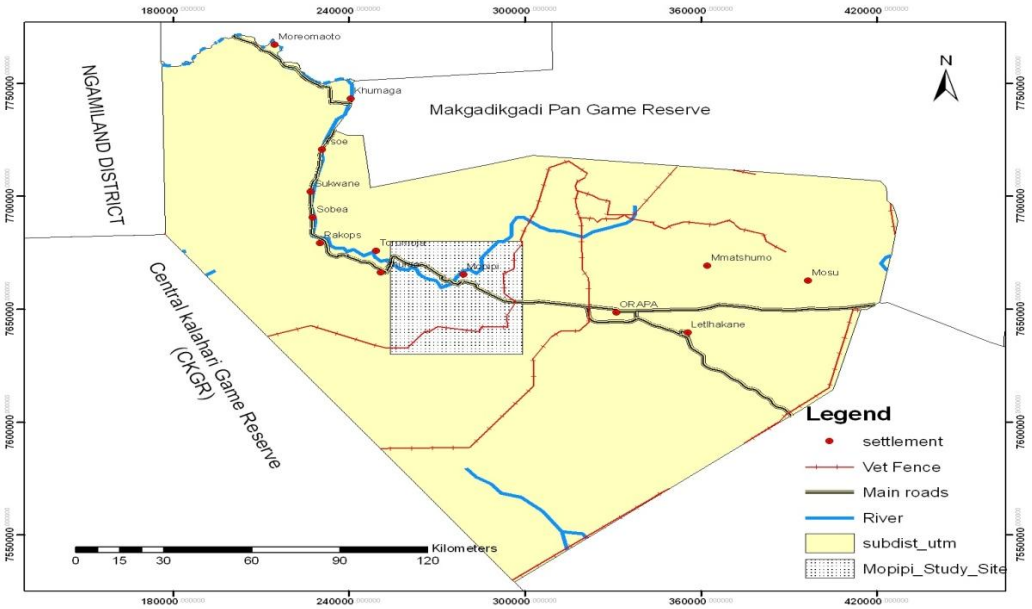

Fig. 1. Map of Boteti sub-district showing the location of Mopipi village
(Source: [27])

The Boteti area is quite diverse in terms of vegetation physiognomy, ranging from woodlands, forests to grass pans [28]. The area acts as an important drainage system for the Boteti River which disintegrates into smaller streams that individually drain into the grass pans of the Makgadikgadi and extending into plains or woodlands/and forests. Common species in the area include *Vachellia erioloba, V. tortilis* and *Colophospermum mopane* trees [28]. *Colophospermum mopane* dominates much of the woodland area in the south and north of Mopipi village. The shrub layer is sparse in both vegetation types but includes *Grewia flava*, *Rhigosum brevispinosum* and *Rhus* spp. The study area is also dominated by plains, as it is a part of the Makgadikgadi basin, which was once a mega lake has dried up over the millennia to leave several pronounced shorelines, for example, the Gidikwe Ridge [29]. The herbaceous cover, density and richness tend to increase proportionately with the distance from the village or the river [26]. The Makgadikgadi depression is mainly covered by grasslands with halophytic species, of which *Odyssea paucinervis* is dominant. *Panicum coloratum var. Makgadikgadiensis* and *Cenchrus ciliaris* also form a major part of the grass association [26].

The study site is located in the tribal land and falls under the jurisdiction of the Ngwato Land Board which has authority over all tribal land within the central district of Botswana. Tribal land in Botswana is communal with free access, hence, its use is also communal except where individuals or groups of people have been granted exclusive rights to use a particular piece of land. Traditionally, Botswana practices a three-tier land use system in the rural areas, consisting of the settlement, arable zone and livestock grazing zone (cattle-post). The arable zone is within the vicinity of the settlement whilst the cattle post is located far from the settlement and is often separated from the arable zone by a drift fence to avoid land use conflict.

According to the 2011 Botswana National Census Statistics, Boteti sub-district has an estimated population of approximately 57376 [30]. The population has increased significantly from 2001 (48, 057) to 2011 (57, 376) with an increase of 9319 (19.4%) which gives an annual growth rate of 1.9 percent which is higher than the national growth rate of 1.8%. The population pressure in the study area is further exacerbated by the fencing of communal rangeland for wildlife and foot and mouth disease control. The village of Mopipi, has an estimated population of 3,912 [30]. Overgrazing by livestock is a prominent driver of degradation in the area [27]. The degradation is marked by large livestock population, the disappearance of most desirable forage species, and decrease in the water table.

2. MATERIALS AND METHODS

2.1 Measurement of Woody Biomass

There is a broad range of methodologies cited in the literature for field estimation of woody biomass. In timber surveys, the 'diameter at breast height' or *'dbh'* is commonly used [31] and features prominently [17]. The diameter at knee height [15] and the diameter at ankle height [21] were also used. The latter appeared to be the most promising, although canopy cover (measured along two perpendicular axes) [18,19,32] has also been used.

The survey of firewood focused on the amount (kg/ha) of both live and dead wood and the consumption rates in relation to the distance (maximum of 14 km) from the village of Mopipi in order to quantify firewood availability. Both the preferred and non-preferred firewood tree species were quantified for both availability and consumption rates. The inventory of all the firewood trees was conducted because some studies have shown that when the preferred firewood trees diminish households tend to switch to the non-preferred species [23,2], suggesting that all tree species are potential firewood.

Transects were deliberately located in the areas where the local people had stated they went to collect firewood. Direct measurements of the firewood tree species in the field were conducted to estimate its availability. Firewood availability across a radius of 14 km was quantified using regression curves formulae [21]. Four transects of 14 km radiating from the village were established and sampling points at 4 kms, 6 kms, 8 kms, 10 kms, 14 kms from the village.

At each sample point, three 50m x 10m quadrats were demarcated using measuring tapes and survey poles. Quadrats of large sizes were discouraged because they have problems of double counting and losing orientation within the quadrat, particularly within dense vegetation [31,33,34]. Thus, rectangular quadrats were chosen (50 m x 10 m) because the longer the quadrats, the more different communities of

vegetation can be captured as compared to square or circular quadrats. The quadrats were demarcated in such a way that their length cut across transects. The distances between the quadrats were 100 m. Individual woody plants rooted within the quadrat were identified; their stem diameters were measured at ankle height (dah) using callipers. Canopy diameters of woody plants were measured twice at a right angle to each other because the cross-section of plant canopy is usually not circular and then the two diameters were averaged to determine the final diameter. The *dah* was selected over the common diameter at breast height (dbh) because woody plants in the study area are dominated by shrubs or low tree savannah, with most of the shrubs multi-stemmed.

A household survey was undertaken to assess the number of people using firewood, the distance travelled from the village to the firewood collection area and the mass of firewood used. These were measured through daily consumption per selected household. Both preferred and non-preferred woody species were recorded. There were 383 households in Mopipi village with an average household size of eight (8) people. Using the Yamane (1967) formula for calculating sample size, the study came up with a sample size of seventy-nine (79) study households. The selected 79 households were interviewed on their use of fuelwood.

The data from direct measurements were analysed using Microsoft Excel and ArcGIS software. The measured stem diameters were converted to woody biomass using the model developed by Natural Resources Project [34]. The collected data were compiled and further analysed with SPSS 1.0.

3. RESULTS

3.1 Biomass of Live Trees

Field survey of the area revealed that vegetation composition varied considerably often over short distances. Table 1 illustrates the distribution of biomass (kg/ha) of live trees at different distances away from the village. Total biomass of live trees increased linearly with distance. The biomass increased from 13,986 kg per ha at 4 km to 34,477 kg per ha at 10 km distance from the village and somehow declined at 12 and 14 km. Biomass was highest at 10 km location and lowest at 4 km. *Colophospermum mopane* contributed the most of the biomass of live trees at most distances with a mean of 11,630 kg per ha. Other plant species that contributed significantly to live woody biomass include *Terminalia sericea, Senegalia mellifera, Terminalia prunioides* and *Mundulea sericea.* The average biomass for all species across all distances (4-14 kms) was 22,595.9 kg per ha.

Though *M. sericea* significantly contributed to the amount of the total live biomass, it is, however, a multi-stemmed and small shrub usually not suitable for good fuelwood collection but, however, it is highly browsable to both game and livestock [35] and its canopy is well distributed within the browse line. Biomass of *A. tortilis, A. mellifera D. cinerea* and *Grewia spp,* was reasonably high at 4 km as compared to 6 and 8 km distances from the village.

Table 1. Biomass (kg/ha) of live trees species at different distance away from the village

Plant spp	Distance from the village (km)						
	4	6	8	10	12	14	Mean
V. tortilis	213.3	6.7	13.3	120	1642..2	486.7	413.7
S. mellifera	203.3	93.3	3577.8	320	2704.4	-	1149.8
Dichrostachys cinerea	503.3	393.3	103.3	783.3	163.3	113.3	343.3
Colophospermum mopane	9411	10183	2889	23517	11749	12027	11629.3
Terminalia prunoides	360	1103.3	20	1103.3	4406.7	-	1165.6
T. sericea	273.3	2183	807	3086.7	380	3676.7	1734.5
Combretum apiculatum	-	-	-	233.3	390	-	103.9
Grewia spp.	1517	493.3	155.3	530	1177.7	383.3	709.4
Boscia albitrunca	-	720	-	-	-	-	120
Mudulia sericea	-	-	2478	660	657.7	1720	919.2
Miscellanous plants	1505	4160	11118	4123	3398	1540	4307.3
Total	13986	19337	21161	34477	26669	19947	22595.9

3.2 Biomass of Standing Dead Wood

Table 2 shows how standing dead wood distribution varies with increasing distance from the village. In general, the amount of standing dead fuelwood showed the same trend as that of live trees (increasing linearly with distance from the village). The amount of standing dead trees, however, declined at 14 km from the village and was 430 kg per ha. *Terminalia sericea* contributed the most standing dead biomass. Other tree species that made significant dead biomass included *Combretum apiculatum* and *Terminalia prunioides.* Standing dead wood occurring at 4 km from the village included that of *A. tortilis, A. mellifera*, and *D. cinerea* amounting to 160 kg/ha while other tree species had no dead wood available. It should be noted here that the latter species are spinescent invader plants (making these species difficult to fetch as fuelwood or browse) and regarded as bush encroachers. The standing dead wood of *C. mopane* was non-existent or very low at 4 and 6 km from the village. Reasonable amounts (that is, 447 kg/ha) of standing dead wood of all tree species occurred at 8 km from the village increasing from 1,486 to 1,897 kg per ha at 10 and 12 km respectively from the village but declined to 431 kg per ha at 14 km distance.

3.3 Utilisation of Firewood

From the households interviewed, it was clear that firewood was the main source of energy in Mopipi Village. All interviewed households collected firewood for themselves and almost all for their needs, particularly for cooking. In some cases, households bought fuelwood from traders in addition to their own collection, at a reported price of P 175.00 (US$10. 03) per van –[25] estimating such loads to weigh up to 300kg. Households rarely collect firewood for other people, except when assisting at funerals or other social gatherings. In Mopipi village, ninety-five percent of households use firewood as the primary energy source for cooking meals. A high percentage (56%) of respondents collect firewood on foot and claims to chop only dead trees whilst 44% buy their firewood or use donkey-cart or their small (1 ton) trucks. None claimed to have never-ever cut live trees for firewood. The frequency of collection of firewood depends on a number of factors, including:

a) The mode of gathering - frequent collectors all carry firewood by head
b) Household size
c) Season of the year – more collection in winter
d) The intensity of use of other energy sources

Preference for tree species used by respondents in Mopipi village is shown in Table 3.

More than 75% of households indicated some problems associated with the firewood collection (Table 4). These include distance from the village and the interference caused by rainfall during the time of collection etc. Seventy-five percent of the households indicated that they encountered problems with firewood availability and rendering firewood an unreliable source for household energy. Respondents were allowed to give more than one answer, of course except if they encountered none. Some 45% of the households indicated gas as the most preferred alternative source of energy. They reasoned that it is most convenient to use and is readily available. Apparently they do not have any ideas of using other alternative energy sources.

Table 2. Biomass (kg/ha) of dead trees at distance away from the village

	Distance from the village (km)						
Plant spp	**4**	**6**	**8**	**10**	**12**	**14**	**Mean**
Dichrostachys cinerea	100	-	6.7	160	-	40	45.1
V. tortilis	40	-	-	71	76	-	37.2
S. mellifera	20	6.7	113.3	-	164.4	-	50.8
Colophospermum mopane	-	5.1	6.7	-	17.8	-	4.9
Terminalia prunoides	-	33.3	95.6	143.3	224.4	60	92.7
T. sericea	-	-	51.3	920	-	333.3	217.4
Combretum apiculatum	-	-	-	42.2	615.5	-	109.6
Grewia spp.	-	4.4	-	148.9	26.7	33.3	35.6
Boscia albitrunca	-	-	-	-	20	-	3.3
Miscellanous plants	-	-	173.4	-	748.9	-	153.7
Total	160	49.5	447	1485.5	1897	430.6	744.4

Table 3. Households response to preferred tree species for firewood

Tree species	Respondent (%)
Colophospermum mopane	88.6
Terminalia prunioides	63.3
S. mellifera	24.3
V. tortilis	6.1
V. erioloba	1.3

Table 4. Problems encountered in firewood supply

Problem encountered	Respondents (%)
Shortage of firewood	24
Expensive of firewood	27.8
Distance to collection sites	36.7
Time spent collecting	2.5
Too much labour	10.1
None	24.6

3.4 Daily Consumption of Firewood

Due to problems encountered in the daily measurement of firewood consumption, an adjusted average use was set at 10 kg usage per day for a household of 8 people. A household of more than 8 people or less would consume more or less firewood, respectively. Problems encountered included, new stocks of firewood being piled on the stock that was to be measured, the loss of substantial firewood stocks due to sales or other multifaceted reasons that often had to do with family relationships.

4. DISCUSSION

Firewood is used in Mopipi village as a source of energy and was used by all those households interviewed. Most of the community relies on firewood as all households consider it to be the main source of energy for cooking, warming bath water and various other family activities such as social ceremonies and funerals. These data concur with those reported in India [36], in Sub-Saharan-Africa [3,37,2,14], in Kenya [4], in Bangladesh [6] and Nigeria [11]. As the use of supplementary energy sources, in particular paraffin, gas and electricity require cash, they are likely to be used only by relatively 'better off' households.

There has been mounting scarcity of firewood within accessible areas of the village. Most firewood is collected from communal land predominantly lying in an easterly direction from Mopipi village. Most households who frequently gather firewood on foot collect it within a range of 4-6 km from the village. This figure fits well with Kgathi [25] who gave an estimate of 4.4 km for head-load firewood collection around Mochudi in southeastern Botswana – where the average head-load weight was estimated as 18kgs, with this load lasting 3 days and taking 2.5 hours to collect [25].

In general, in Mopipi village, as in the other parts of the country, the collection of firewood is mainly the responsibility of women and children. But if donkey-carts or vans are used, men are also often involved. With the depletion of wood resources in areas closest to homesteads, more time is spent in firewood collection thus depriving children of study-time and women of other productive chores such as commercial activities, adult education, or participating in village governance structures [7]. Collection of firewood is typically an individual household activity for their benefit. Households rarely collect firewood for other people except for social gatherings such as weddings or funerals. The majority of households collect firewood at least once per week. The frequency depends on the mode of transport used, for example, gather firewood by head or use of donkey-cart or vans. The season of the year and the size of the household also contributes to the frequency of firewood gathering [2].

Colophospermum mopane contributed the most biomass of live tree species but its standing dead wood was estimated to be less than that of less abundant species such as *T. sericea* or *D. cinerea. Colophospermum mopane* is a preferred firewood species, but it is only available as standing deadwood far from the village. Trade-offs are clearly involved with people collecting less preferred species such as *T. sericea*, available at closer distances, rather than trek further for higher quality firewood. In many parts of Botswana, there are preferred tree species that households would normally collect for their energy needs. This preference may be guided by some traditional norms but largely by the efficiency of the burning of that particular wood species. For example, in northern and eastern Botswana, *C. mopane* and *Combretum imberbe* are regarded as the best and therefore are most preferred. *Terminalia prunioides, S. mellifera* and *D. cinerea* are also popular firewood species, although the spinescence of the latter two make them difficult to collect – which is unfortunate as they are encroaching upon the heavily grazed rangeland around the village. *Senegalia mellifera* and *D. cinerea* usually occur as a result of land disturbance (overgrazing, cultivation etc), hence their relative dominance at lower distances from the village and *M. sericea* (a benign browse

species) *was* not present beyond 4 km from the village.

Detailed studies such as Niger [38], have highlighted the merits of traditional methods of harvesting the natural woodlands and the need to build upon management systems that are familiar to the local population and so easily implemented. For firewood purposes, it would be beneficial if the transformation of bushes around the village into trees could be encouraged. It may be considered by district authorities to set aside an area close to the village as a wood-lot of indigenous or well performing exotic species in which the plantation is managed by the community.

The biomass of live trees was reasonably high at distances near the village concurring with households claims made during the survey that they tend not to harvest live trees but only harvest dry wood. Government Projects in the arable sector in the 1980s that encouraged the clearance of relatively 'pristine' areas of Savannah by offering destumping and ploughing subsidies were greatly criticized for the widespread clearance of land they effected [39]. Apparently, many of these effective subsidies have recently been re-introduced under newly branded projects as the Botswana Government's drive to increase food production in the rural areas. Consequently, such projects contribute significantly to the loss of firewood near villages and also to environmental degradation [5,40,41]. One of the most significant impacts of the unsustainable use of natural resources is deforestation [5,37,41,7,2]. Deforestation leads to an increase in greenhouse gas emissions and a consequent acceleration of climate change impacts [2].

Bushes are also cleared for the usage as livestock kraals, poles for fencing arable lands and for building homesteads, although such clearance tends to be localised and relatively insignificant compared to that cleared to take advantage of the various subsidies now available in the arable sector. Artzen and Veenedal [42] estimated that nationally 1.7×10^5 tonnes/year of firewood was used in the fencing of kraals and 0.34×10^5 tonnes/year in the construction of buildings. Unlike firewood consumption, these poles are taken from live trees, with stem diameters in the range of 8 cm which are required to provide the necessary support for construction.

Bush and pole fencing for arable lands in order to keep livestock out of the crops is still a common practice in the rural areas of Botswana, due to comparative expensive wire fencing measures. The amount of wood required to bush and pole fence an area of 4.6 hectares has been estimated at 30 tonnes, with 6 tonnes required annually for renewal [43]. Clearance for arable cultivation can, therefore, generate firewood in the short term, although by depleting the woody biomass resource, it is likely to be detrimental to firewood supplies. This is especially so where land clearance is followed by soil and nutrient loss, via wind and water erosion [44]. In the early 1990s, Significant studies in the Sahel region concluded that, *'it has been a grave error to think that firewood has come from the exploitation of the natural savanna when, in the great majority of cases, it comes from deadwood in areas cleared for agriculture'* (Catinot and Bonkungo [38]).

5. CONCLUSION

In Mopipi village, poor households will undoubtedly remain in an effective poverty trap as alternative energy supplies remain out of their financial reach and the hardship of collecting natural firewood from increasing distances from the village will increase. Unless alternative and more sustainable solutions are found it can be expected that the future will bring ever-increasing firewood harvesting distances; a continued rise in prices of firewood; increased cutting of live trees; probable introduction of more lorries in fully privatised operations for transporting firewood to the schools, hospitals and other private sectors as distances to the source areas increase and access become more difficult. In the long-term, demand for firewood in Botswana must be augmented by using alternative energy resources such as electricity, biogas, dry cow-dung, coal and solar energy. Furthermore, establishing firewood plantations manned by the community and also the use of wood-efficient stoves could proof to be an effective way of reducing the rate of consumption of firewood and thus saving time of women and children spent in collecting firewood.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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