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Fuelwood Production and Carbon Sequestration in Public Urban Green Spaces in Bulawayo, Zimbabwe

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Abstract: Trees in public urban green spaces provide a variety of ecosystem goods and services that are greatly appreciated by urban residents. A commonly used good, especially in Global South regions, is that of fuelwood for household energy needs. Yet the production potential of fuelwood from public urban green spaces has rarely been examined. This study quantifies the fuelwood production and allied carbon sequestration potential of 12 public urban green spaces in Bulawayo (Zimbabwe) stratified across neighborhoods of different housing densities. We estimated tree density in the green spaces by means of line transects, and annual production through estimates of the mean annual increment of a sample of marked trees. We found that Bulawayo's public green spaces produce 1.9 t/ha/yr of fuelwood with a value of $340 to $490/ha/yr, and that production varied across spaces and housing density neighborhoods. This production is much lower than the documented demand but it is likely to be significant for fuelwood-dependent households. In contrast, the amount (1010 ± 160 kg/ha/yr) and value (US$4.04/ha/yr) of carbon sequestration were lower. Formal public green spaces produced more fuelwood as compared to informal green spaces and no difference was evident in tree growth rates between exotic and indigenous tree species. This is one of the first studies to show the value of the fuelwood production and carbon sequestration potential of public green spaces in the region and continent and requires that they are integrated into public urban green space policies, planning, and management in the city.

Keywords: carbon sequestration; fuelwood; green space; housing density; production; value

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1. Introduction

Urban green spaces and forests provide an array of ecosystem services [1,2] and disservices [3,4] to urban residents. In the Global North, the most used and valued services relate to recreational use and regulating services. In contrast, in many Global South contexts provisioning services are highly used and valued, especially by the urban poor [5,6]. These include the provision of water, wild foods, traditional medicines, building and roofing materials, decorative materials, and biomass energy for cooking and heating [7–9] for both household use and income generation.

Biomass, which includes fuelwood, is the cheapest and oldest form of energy used by humankind and is traditionally used via direct combustion [10,11]. Although the use of fuelwood is most common in rural areas of the Global South, it is also widely used in urban and peri-urban contexts too [7,12,13]. There are varying reasons why urban residents might use fuelwood [14]. A common one is the limited physical or financial availability of modern energy sources such as electricity or gas in many regions [15–17]. Additionally, the high costs of appliances, such as electrical stoves, can also limit the uptake of modern energies [14,18]. However, some individuals use fuelwood for cooking because they enjoy the taste of food cooked over a fire and, for others, tradition requires certain foods to be cooked over a fire [16,19,20]. Much of the urban fuelwood demand is typically met by stocks harvested from adjacent or even distant rural areas and sold in urban markets [12,17,21].

The commercialization of fuelwood can have positive effects by providing energy for urban residents who are not able to collect the wood themselves and also the provision of income for vendors [19,21,22]. Nevertheless, wood harvested from formal and informal urban green spaces can be vital for the energy security of some urban residents, especially the poor [23]. Consequently, the potential of fuelwood to aid in poverty reduction in urban areas should be integrated into forestry and energy supply plans to support development whilst maintaining the natural resource base [24].

Excessive or unsustainable harvesting of fuelwood from urban and peri-urban spaces can lead to marked transformation of urban green spaces as tree canopy and density diminish [25–27]. Reductions in woody biomass can, in turn, result in the loss or impairment of many other ecosystem services, such as carbon sequestration, temperature amelioration, erosion control, aesthetic appeal, and habitat for other species, amongst others. Thus, unsustainable harvesting of wood for fuel usually represents a trade-off against other benefit flows; with carbon sequestration being of interest in our study. In contrast, sustainable use can provide energy to the poor with zero or low net emissions to the atmosphere [28–30]. Consequently, there is a need for careful monitoring and management of urban biomass that might be used for fuelwood purposes.

Although urban forests store carbon, the overall benefit is likely to be small because they constitute only a small fraction of urban areas [31] and anthropogenic emissions in urban areas are typically high, usually dwarfing the amounts sequestrated by urban trees. For example, in the Twin Cities area of Minnesota (USA), urban trees sequestered only 1% of emissions [32]. From 2004 to 2006, the urban forests in Shenyang (China) were estimated to offset only 0.7% of the carbon emissions from fossil fuels in the city, which were estimated at 11.6 million tons annually [33] despite urban green infrastructure comprising 22% of the city area. From these figures, it is evident that currently urban green spaces contribute, but not much, towards CO_2 pollution reduction. However, Nowak et al. [34] opine that urban forests mitigate climate change but are not well understood, resulting in them being disregarded as a mitigation option in many countries. With proper planning and optimization of planting opportunities, the extent of carbon sequestration and biomass production of urban forests could be greatly enhanced [35,36].

In Zimbabwe, fuelwood is an integral part of the energy mix of urban households. For example, Mapira and Munthali [19] reported that in Masvingo, the domestic energy mix was typically made up of fuelwood (30%), candles (24%), electricity (24%), paraffin (13%), and other (9%; solar, torch batteries, generators, gas, diesel, cow dung, and jelly). In terms of the proportion of households using a particular energy, fuelwood was the highest, followed by electricity and paraffin. In contrast, in Bulawayo, Dube et al. [37] found that after electricity, fuelwood was used the most (76%), followed by paraffin (10%), gas (7%), jelly fuel (6%), and coal (1%). The use of fuelwood in Zimbabwe is underpinned by the poor and erratic supply of electricity. This is attributed to the failure of the national power supply authority to maintain the infrastructure, and recurrent droughts that constrain the production of hydroelectricity at the Kariba dam [38], resulting in residents having to depend on other forms of energy. Zimbabwe has two major power stations, the Kariba hydropower station and the Hwange thermal power station. Zimbabwe has the potential to generate 1870 MW against a peak demand of 2500 MW. Some of the deficit is met through imports of electricity from neighboring countries, namely Mozambique, South Africa, and the Democratic Republic of Congo [37]. Bulawayo has a small power station with a capacity of 90 MW but it usually generates only a third of that. Dube et al. [37] reported a high correlation between the duration of electricity cuts in Bulawayo and the use of fuelwood as a substitute fuel. Fuelwood consumers in Bulawayo prefer indigenous species, evident by the high use of *Vachellia* species and low use of exotic species such as *Eucalyptus* and *Jacaranda* [37]. This is attributed to indigenous trees having better burning qualities, lasting longer, being easily available, and not emitting unpleasant smells during burning [37].

Open burning of fuelwood is associated with adverse health effects such as respiratory ailments [39]. Consequently, open-air burning of fuelwood is often discouraged to reduce indoor air pollution and the actual quantities of wood used [11,40]. Alternative means of the use of fuelwood to generate energy include (i) improved cookstoves [41] or (ii) the generation of electricity in wood-powered plants [42]. Michigan (USA), for example, supports a 35 MW power plant designed specifically for burning urban wood sourced from dead and dying trees which are routinely removed from urban green spaces [42]. The annual yields of wood biomass from dead and dying urban trees in 2.2 million ha of Michigan are the equivalent in energy content to between 367,000 to 517,000 dry tons of biomass which is equivalent to a 97.5 MW power plant. Viewed at the national scale, the routinely removed urban biomass in the USA could supply 2.8 million people per year with electricity, which in turn saves $48 to $132 per ton across the USA in landfilling costs [42]. This is an indicator of the potential that urban fuelwood has in improving the livelihoods of urban residents by providing affordable energy and could further add to the economic reasons for the maintenance of urban woodlands [26].

Despite the widespread and well-researched use of fuelwood by urban populations, there are relatively few studies that have quantified the production potential of urban forests for fuelwood production or as a potential trade-off with carbon sequestration. Consequently, fuelwood production has rarely been included in the valuation of ecosystem services provided by urban forests, and rarely does sustainable harvesting of fuelwood feature in urban forest management objectives and plans. In this light, the objective of this study was to determine the fuelwood production, or alternatively the carbon sequestration potential, in public green spaces in different residential housing areas in Bulawayo. The study answered the following two questions: (i) What is the rate of wood production and carbon sequestration potential in public green spaces in Bulawayo? and (ii) What is the value of the wood production and carbon sequestration from public green spaces in Bulawayo?

2. Materials and Methods

2.1. Study Area

This study was conducted in Bulawayo (20°9′0′′ S; 28°35′0′′ E), the second-largest city in Zimbabwe. Bulawayo is located at an altitude of 1353 m in the savanna biome and is characterized by a sub-tropical climate with warm summers (September–April) and mild winters (May–August) [43]. The average summer temperatures range from 14 to 29 °C, but temperatures above 32 °C are common throughout the summer, and over 35 °C at times. The mean annual rainfall is 570 mm, received mostly between October and April.

As described by Ngulani and Shackleton [44], the city currently covers 546 km^2 with a population of 653,377 persons, and it is growing at approximately 1.8% per annum. It has 165,345 households with an average size of about 3.9 persons [45]. Just over half (54%) of the population is male [45]. The literacy rate is 96% for ages 15 and above [45]. Bulawayo is divided into 29 wards which are a mixture of low-, middle-, and high-density neighborhoods. The city has historically been known as the nation's industrial hub. However, this is within the context of Zimbabwe being amongst the lowest 15% of nations in terms of GDP per capita (approx. US$995 in 2016). The main economic activities include heavy and light industrial manufacturing, public transport, public services, and informal trade.

Various public green spaces such as parks, playgrounds, golf courses, nature reserves, and urban forests occur in the city and many roads are lined with trees [43]. The city has 47 formal and informal public green spaces: 22 in the more affluent, low-density housing areas, five in medium-density areas, 19 in the low-income, high-density neighborhoods, and one in the industrial zone [44]. According to the now-dated (1981) Bulawayo master plan, formal and informal green spaces make up 6.4% of the city area, or approximately 3500 ha. The city's green spaces are a mix of open and treed areas. Tree density ranges from 40 to 95 trees per hectare, with the most common species being *Eucalyptus* spp., *Vachellia gerrardii*, *V. nilotica*, *Azanza garkeana*, *Peltophorum africanum*, and *Pinus* spp. [46].

2.2. Methods

Four public green spaces were randomly selected in each of the low-, medium-, and high-density neighborhoods from a list of green spaces provided by the city authority. In the high-density areas, the green spaces were Luveve, Mpopoma, Nketa, and Nkulumane; in the medium-density areas, they were Barham Green, Northend, Parddonhurst, and Queenspark; and in the low-density areas, we sampled Famona, Hillcrest, Hillside, and Khumalo public green spaces. The distribution, size and conditions of the sampled green spaces are presented by Ngulani and Shackleton [44].

Thereafter, the density of trees per green space was sampled using randomly located belt transects. Each transect was 4 × 100 m. For each tree taller than 2 m within a transect, the height and diameter at breast height (DBH) were recorded. If the tree was multi-stemmed, all stems were recorded. The number of transects per green space varied in relation to the size of the green space and the proportion that was treed, ranging between four and nine per space. A total of 53 transects were sampled. Any signs of chopping were recorded.

The allometric equation (Equation (1)) of Mugasha et al. [47] from Tanzania was used to convert the height and DBH readings to biomass per stem, and Equations (2) and (3) in Nowak and Crane [48] were used to determine total carbon sequestered for conifers and hardwoods, respectively.

$$\text{Biomass} = 0.0763\ \text{dbh}^{2.2\circ 46}\ \text{ht}^{\circ.4918} \quad (1)$$

$$\text{Carbon sequestered for conifers} = \text{Biomass} * 0.48 \quad (2)$$

$$\text{Carbon sequestered for hardwoods} = \text{Biomass} * 0.56 \quad (3)$$

Secondly, the annual production of biomass per green space was determined by measuring the annual stem diameter increment. A total of 173 trees were marked in the 12 green spaces in September 2014 and re-measured in September 2015. Equation (1) was used to determine the biomass per stem in 2014 and again in 2015, the difference in which was then converted to wood production in kg/ha/yr. This was then multiplied by the carbon conversion factor to determine carbon sequestration.

SPSS v20 was used to analyze the data. ANOVA was used to determine differences in wood production rates amongst green spaces. A *t*-test was used to determine the difference in production rates between formal and informal green spaces and to determine the relationship between wood production and the origin of trees (i.e., indigenous or exotic).

Thirdly, the value of fuelwood was calculated by determining the market price for wood from the three residential classes by averaging the selling price from four fuelwood vendors per residential zone and using the calculated value to determine the value of wood per kg. This value was then used to determine the value of fuelwood provision in Bulawayo's urban green spaces in kilograms per hectare per year. The value of carbon sequestration was determined as the prevailing international price per ton when the fieldwork was conducted (2014/2015), which was US4.00 [49].

3. Results

3.1. Tree Density

Tree density in Bulawayo's public green spaces generally decreased with increasing neighborhood housing density (Table 1) though the difference in means was not significant ($F = 2.3$, $df = 2$, $p > 0.05$). Mean tree density in the low housing density areas was 86 ± 10 trees/ha, which was 25% higher than the 61 ± 29 trees/ha recorded in the high-density areas, with the medium housing density areas intermediate between these two. Khumalo and Hillside, both in low-density housing neighborhoods, Parddonhurst (medium density) and Nketa (high density) had high tree densities per hectare. Luveve (high density) had the lowest tree density per hectare.

Table 1. Tree density in public parks in Bulawayo across three residential housing density areas.

Housing Density	Public Green Space	Size (ha)	Density (Trees/ha)	Mean Density (Trees/ha)
Low	Hillcrest	14.9	80	86 ± 10
	Khumalo	16.5	95	
	Famona	4.2	75	
	Hillside	4.8	95	
Medium	Northend	5.7	70	69 ± 19
	Parddonhurst	4.3	95	
	Queens Park	7.9	60	
	Barham Green	6.5	50	
High	Mpopoma	3.9	50	61 ± 29
	Nketa	5.9	95	
	Luveve	4.7	40	
	Nkulumane	38.3	43	
Mean			74 ± 21	

3.2. Rate of Wood Production

3.2.1. Wood Production per Green Space and Residential Density

Wood production per green space ranged from about 405 to 3713 kg/ha/yr with a mean of 1890 ± 167 kg/ha/yr (Table 2). This equates to about 6600 t/yr across the entire city since green spaces cover approximately 3494 ha. With a population of about 653,000 residents and 165,345 households [45], this provides 0.04 t/hh/yr and 0.01 t/ca/yr.

Table 2. Wood generated per green space per year.

Housing Density	Public Green Space	Nature	Wood Production (kg/ha/yr)	Mean (kg/ha/yr)	Carbon Sequestration(kg/ha/yr)	Mean (kg/ha/yr)
Low	Hillcrest	Informal	2063	2455 ± 910	1062	1296 ± 252
	Khumalo	Informal	3713		2018	
	Famona	Formal	1590		869	
	Hillside	Informal	2452		1234	
Medium	Northend	Informal	2895	1361 ± 1104	1590	742 ± 301
	Parddonhurst	Informal	1410		739	
	Queens Park	Informal	405		227	
	Barham Green	Informal	735		412	
High	Mpopoma	Informal	1103	1853 ± 1067	617	994 ± 274
	Nketa	Formal	2865		1510	
	Luveve	Formal	2670		1414	
	Nkulumane	Informal	773		433	
Mean for all green spaces				1890 ± 1067		1010 ± 160
Mean for formal green spaces				2375 ± 687		1264 ± 200
Mean for informal green spaces				1728 ± 1122		926 ± 205

The highest wood production rates were recorded in Khumalo (low-density neighborhood) Northend (medium density) and Nketa (high density), and the lowest in Barham green (medium density), Queenspark (medium density), and Nkulumane (high density). There was a significant difference between growth rates among the different green spaces ($F = 2.642$, $df = 11$, $p < 0.05$). The post hoc Tukey test showed that the mean fuelwood production in Luveve significantly differed from Famona, Hillcrest, Hillside, and Nkulumane ($p < 0.05$). However, there were no significant differences between housing density classes ($F = 1.65$, $df = 2$, $p > 0.05$).

3.2.2. Wood Production in Informal and Formal Green Spaces

Out of the 12 sampled green spaces, three were formal and nine were informal. The mean production rate of formal green spaces (2375 ± 687 kg/ha) was significantly higher than that of informal green spaces (1738 ± 1122 kg/ha) ($t = 3.2$, $df = 109$, $p < 0.05$) (Table 2). The highest wood production rates were recorded in Khumalo (informal), Northend (informal), Nketa 6 (formal), and Luveve (formal), and the lowest production rates were determined in Queens Park, Nkulumane, and Barham Green (all informal).

The mean carbon sequestration rate in the different residential areas ranged from 227 to 2018 kg/ha/yr (Table 2), with a mean of 1010 ± 160 kg/ha/yr. Green spaces cover approximately 3494 ha in Bulawayo and therefore Bulawayo's urban green spaces sequester about 3529 t of carbon per annum. The three highest areas of carbon sequestration were in Khumalo (low density), Northend (medium density), and Nketa (high density), and the three lowest were in Queens Park (medium density), Barham Green (medium density), and Nkulumane (high density). The annual rates differed significantly between residential classes ($F = 3.69$, $df = 2$, $p < 0.05$), being lowest in the medium areas and highest in the low-density areas, because of higher tree densities.

Formal green spaces had a significantly higher mean carbon sequestration rate (1264 ± 200 kg/ha/yr) as compared to informal green spaces (926 ± 204 kg/ha/yr) and ($t = 2.20$, $df = 10$, $p < 0.05$) (Table 2). The four sites which sequestered the lowest carbon per hectare per year were all informal green spaces and the highest sequestration was recorded in an informal green space. Carbon sequestered was positively related to tree size ($F (1, 114) = 246.3$, $p < 0.05$, $R^2_{Adj} = 0.54$, y = carbon sequestration = $3.55x + 8.22$), (Figure 1).

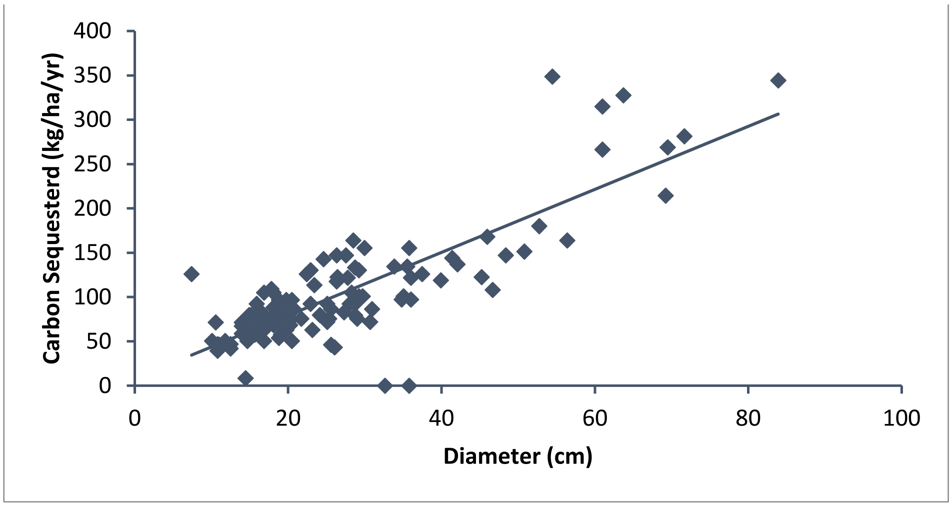

Figure 1. The relationship between carbon sequestered and stem diameter.

3.2.3. Origin of Tree Species

The majority (67.6%) of trees in the 12 public green spaces were indigenous and 33.4% were exotic. The most common species were *Eucalyptus* spp., *Vachellia gerrardii*, *V. nilotica*, *Azanza garkeana*, *Peltophorum africanum*, and *Pinus* spp. In the formal green spaces, 42.1% of the trees were exotic and 57.9% indigenous; the ratio was almost identical in the informal spaces (42.3% and 57.7%, respectively). No relationship was evident between the nature of green space and origin of trees ($X^2 = 0.979$, $df = 1$, $p > 0.05$). Differences in wood production rate and origin of trees were tested. The wood generation for indigenous species was 193.2 ± 115.5 kg/ha/yr and that of exotic species was 189.0 ± 92.1 kg/ha/yr (t = 0.2, df = 84.9, $p > 0.05$).

3.2.4. Value of Wood Provision and Carbon Sequestration

The average cost of fuelwood was US$0.25 per kg in the high density and medium density areas and US$0.20 per kg in the low-density areas, giving an average cost of US$0.23 per kg. Based on the annual wood production rates recorded, the potential value of fuelwood provision in Bulawayo's urban green spaces ranges from US$340 and US$463/ha/yr (Table 3). The low-density housing areas recorded the highest value, followed by high-density areas, and medium-density areas recorded the lowest value.

Table 3. Annual value of fuelwood produced in sampled green spaces.

Housing Density	Wood Production (kg/ha/yr)	Fuelwood Price (US$)	Wood Value (US$/ha/yr)	Carbon Value (US$/ha/yr)
High	1853	0.25	463	3.97 ± 1.90
Medium	1361	0.25	340	2.97 ± 1.20
Low	2455	0.20	491	5.18 ± 1.00
Mean	1890 ± 548	0.23 ± 0.03	431 ± 80.3	4.04 ± 1.44

The value of carbon sequestration as an ecosystem service was determined by the amount of carbon sequestered (Table 3). The mean carbon sequestration was 1010 ± 160 kg/ha/yr with a value of US$3.70/ha/yr. Khumalo green space was determined to have the highest carbon sequestration value (US$8.02/ha/yr), followed by Northend (US$6.36/ha/yr) and Nketa (US$6.04/ha/yr). Low-density green spaces recorded the highest value (US$5.18/ha/yr) and medium-density recorded the least (US$2.97/ha/yr).

4. Discussion

4.1. Fuelwood Production Rates and Carbon Sequestration

Bulawayo's urban green spaces produced an average of 6600 tons of fuelwood per year. The results show that the production rates amongst the three residential classes and amongst the 12 green spaces were significantly different from one another. Growth rates are influenced by both environmental and anthropogenic effects. The mean fuelwood production rates decreased as residential density increased. This is likely to be due to the general decrease in tree density as residential density increased, reflecting greater use of urban green spaces for provisioning services in the poorer neighborhoods [37,46], and perhaps the impacts of urban livestock, most commonly found in the high-density areas, on tree regeneration [50]. Thus, the high-density housing areas were the areas with the greatest need for local fuelwood supplies yet had the least production [37]. The lower tree density and production in the high-density neighborhoods may also be a reflection of unsustainable use in the areas of greatest demand.

The estimated yield of 6600 t of fuelwood per year translates to 0.04 t/household/yr and 0.01 t/ca/yr. Dube et al. [37] determined annual fuelwood use per capita to range from 1.1 to 1.8 t per household in Bulawayo. Thus, fuelwood supply from the public urban green spaces supplies only 5–11% of the annual demand. This is not surprising as public green spaces cover only 6.4% of Bulawayo's land area. At a city scale, the gap in fuelwood supply is currently covered mostly by fuelwood sourced from traders who import fuelwood from surrounding rural areas, as is the case with most large cities using extensive amounts of biomass [22,51,52]. Nevertheless, at a household scale, it is quite probable that some households source a significant proportion of their fuelwood needs from urban green spaces, especially informal ones. The contribution of private spaces and trees also needs to be factored in [5]. The household fuelwood consumption rate in Bulawayo is quite high compared to other regions. For example, in the Himalayan region of India where the consumption of fuelwood is 61 kg/ca/yr [53]. Fuelwood consumption in a village in Sahel, Mali, ranged from 1.4 to 0.8 kg/ca/day depending on household size [54] and a study of 3000 households across 10 rural agro-ecological locations in Sub-Saharan Africa determined fuelwood use to be 2.2 kg/ca/day [55]. In Uganda, fuelwood consumption was determined to be 1.56 m^3/yr for a household of about seven persons [56].

As an alternative use or trade-off to fuelwood, this study has shown that carbon sequestered in a sample of Bulawayo's green spaces ranges from 227 to 2018 kg/ha/yr, with a mean of 1010 $\pm$ 160 kg/ha/yr. With approximately 3490 ha of public green space in the city, Bulawayo's urban green spaces sequester about 3329 tC/yr. This is relatively small compared to estimates from cities in other countries. For example, in the Charlotte Metropolitan Region, USA, the total amount of carbon stored in the local forests is 3.8 million t/yr [57], reflecting a larger city and with a greater coverage of green space. The inner city of Melbourne (Australia), with approximately 10,000 trees, is estimated to sequester one million tC/yr [58]. Canopy cover was approximately 19% of the urban area in Leipzig, Germany, where above-ground carbon storage was estimated to be 11 tC/ha/yr [59]. In 2002, the city of Tshwane, South Africa, developed a strategy to plant 115,200 indigenous street trees which were estimated to sequester 54,630 tC/yr [60]. The currently small carbon sequestration potential of the urban forest in public parks of Bulawayo could be used as a catalyst to prompt the city authorities to revise the city plan for more public green spaces and perhaps greater canopy cover. However, the goal of increasing carbon sequestration could be at odds with citizens' needs for fuelwood, some of which is locally sourced, especially from the informal green spaces. This could be accommodated by (i) designating particular areas for fuelwood supply and establishing community woodlots in informal green spaces stocked with hardy species that readily coppice, such as in Ethiopia [61] and Rwanda [62], and even in Global North settings such as Leicester in the UK [36], or (ii) establishing depots for wood generated via tree trimmings from park and street maintenance operations. In addition to urban green spaces, carbon may be sequestered by other vegetation within the city such as street trees and vegetation in domestic homesteads [31], corporate grounds, and parking lots [35]. Urban trees had the highest storage of carbon (28.9 kg/m^2) in Leicester's (UK) publicly-owned areas as compared to domestic gardens (0.76 kg/m^2) and herbaceous land cover (0.14 kg/m^2) [63]. Although the same pattern may not be true for Bulawayo due to differences in location and city design, this is an indication that public urban green spaces sequester a considerable amount of carbon when compared to other areas within the city as most of the areas are generally built-up areas.

As to be expected, a significant, positive relationship was determined between tree stem diameter and carbon sequestered, which was the basis of the allometric equation to determine biomass. This is supported by Nowak and Crane [48] who showed that if urban tree cover is increased, it will result in an increase in carbon storage and sequestration because large trees sequester about 90 times more carbon than small trees. Similarly, Stoffberg et al. [60] argued that larger trees with higher growth rates are more beneficial in ameliorating global warming by sequestering more carbon than the smaller trees. Tree species that attain large sizes may be selected if they are solely planted for the function of carbon sequestration. This is not always possible for street trees because large street trees may interfere with utilities, signage, and road expansion [64], but expansive urban green spaces are ideal for large trees. However, large trees are declining in urban areas globally [65].

Both indigenous and exotic species were found in Bulawayo's public urban green spaces. However, according to Ndlovu (pers comm, 8 October 2014) exotic trees are mostly planted along streets and in formal green spaces. Those occurring in informal spaces have self-seeded and may include invasive species. Previous studies in sub-Saharan Africa show a general preference for indigenous species for fuelwood purposes. This is because they are better known, often more easily accessible, and are typically of denser wood which provides longer-lasting coals, providing a more even heat [37]. In contrast, many exotic species have lighter wood which burns too fast and may also be associated with unpleasant odors [37]. However, in the face of fuelwood shortages or easier accessibility, exotic species will be used [22,61]. Species that supply fruit or have medicinal properties are less likely to be cut for fuelwood [37].

4.2. Fuelwood Production and Green Space Type

The formal public green spaces produced more fuelwood and sequestered more carbon on a per unit basis than the informal spaces, despite similar tree densities. This is likely to be a reflection of the more intensive management and protection in the formal public green spaces, which would, over time, result in larger trees. Bulawayo's formal green spaces are regularly patrolled by council officers and residents are ostensibly not permitted to cut trees for fuelwood or any other purpose. Cutting is also disallowed in informal spaces, but there is far less enforcement in informal green spaces. The formal public green spaces also enjoy, at times, greater management, such as the pruning of trees, mowing of the understory grass, and sometimes irrigation. The latter likely improves growth and also survival. For example, Koeser et al. [66] reported a 98% survival rate amongst irrigated urban trees in Florida (USA), compared to only 74% for non-irrigated ones.

Although the informal green spaces produced less fuelwood per hectare than formal green spaces, this could be reversed if desired by local citizens. This could be achieved via one or more means, such as through enrichment planting, community woodlots, or coppice rotation of wood harvesting. A community woodlot approach can be more effective in managing fuel shortages if it is with participation from residents, if the population density is not too large to avoid deforestation and if access to these areas is regulated [61]. However, any trade-offs with other uses of the informal green spaces would have to be assessed, such as for recreational or spiritual uses.

4.3. Value of Fuelwood Provision and Carbon Sequestration

At the time of fieldwork, the price of fuelwood in Bulawayo averaged $0.23 per kg, being $0.25 per kg in the medium and high-density areas and $0.20 per kg in the low-density neighborhoods. The slightly lower cost of fuelwood in the low-density areas may be attributed to lower demand as compared to the other density classes because they are in a position to use more costly alternative sources of energy such as liquid petroleum gas and petrol- or diesel-powered generators in the absence of electricity.

The determined value of fuelwood provision as an ecosystem service in Bulawayo was $340 to $490 ha/yr. The growing of trees for the provision of fuelwood can be compared with other ecosystem service values from urban trees such as air purification, urban cooling, and climate regulation. In Chicago, USA, McPherson et al. [67] determined the value of air purification to be $9.2 million/year and $15/tree/year for urban cooling. No comparisons could be made for local studies as such studies have not been conducted.

Trees both in urban and rural green spaces serve various purposes which in some contexts might necessitate trade-offs. For example, some uses are destructive, such as harvesting timber and fuelwood, whilst others promote conservation such as revering trees for spiritual reasons or maintenance for carbon sequestration purposes. In Bulawayo, the value of carbon sequestration was determined to be $4.04/ha/yr and about $14,000 per year for the whole city. This is very low in comparison to other places, such as $1.19 million in Shayang, China [33]. The total amount of carbon stored in the local forests in Charlotte Metropolitan Region (USA) was determined to be 3.8 million tons worth $298 million with an average carbon density of 53.5 t/ha [57]. The above values show that if future trade becomes operational for urban forests, the forests have the potential to reduce greenhouse gases and to potentially become a valuable source of revenue for the municipality [60]. In Barcelona, the total biophysical value of net carbon sequestration is estimated at 5187 t/yr and 536 kg/ha/yr with an economic value of $407,000/yr. This value considered the net carbon sequestered taking into account the maintenance of green spaces [31]. As mentioned before, trees are multifunctional, and therefore decisions on the conservation of green spaces as well as the establishment of new green spaces can be guided by the value of carbon sequestration and/or fuelwood as an ecosystem service.

The fuelwood and carbon sequestration values reported in this study are not additive, because if biomass is harvested for fuelwood, the carbon sequestered to produce that biomass is returned to the atmosphere. Thus, there is a trade-off and which of these two ecosystem services is deemed the most important for local people needs to be considered in future green space planning and management in Bulawayo. The use of fuelwood is regarded to be more or less carbon neutral in terms of emissions contributing to climate change [28–30]. However, Holtsmark [68] argues that such an assumption is too simplistic, and further consideration is required in terms of the regrowth rates of the harvested biomass and how harvesting effects soil carbon dynamics. Nevertheless, it is still deemed to have far lower emissions than fossil fuels.

With the current shortage of modern energy supplies to Bulawayo and with pervasive poverty, fuelwood is likely to remain a key component of the domestic energy mix for some time to come. Our study shows that the annual value of fuelwood from Bulawayo's public green spaces is two orders of magnitude greater than their value for carbon sequestration. (Note, however, that the price of carbon has increased approximately twenty times since the time this study was conducted). However, the lower tree density found in the high-density neighborhoods and the lower productivity of informal green spaces suggest that current levels of fuelwood extraction are likely to be unsustainable. That is hardly surprising given that the city's public green spaces produce only 5–11% of the annual demand for fuelwood. This requires that the city authorities develop appropriate plans for energy supplies and security on the one hand, and public park maintenance on the other. Whilst there are some approaches that may allow the two to overlap spatially, the large magnitude of fuelwood demand may require the separation of fuelwood supply sites from aesthetic public parks, through strategies such as fuelwood plantations or reserved areas of informal green spaces.

5. Conclusions

Bulawayo's green spaces produce 1.9 t/ha/yr of fuelwood with an ecosystem service value of $340 to $490/ha/yr. The green spaces showed a significant difference in fuelwood production among sites. Previous studies have determined fuelwood consumption in Bulawayo to be 1.1 to 1.3 t/ha/yr [37] and this study determined that the fuelwood production rate is much less than the consumption rate. This shows that although the public green spaces may not meet all the fuelwood demands of Bulawayo's residents, the green spaces are capable of making some contributions in this regard, and that this function has a high value, likely to be much higher than the limited maintenance budgets for green spaces in Bulawayo. In contrast, the value of carbon sequestration by trees in public spaces in Bulawayo is modest. Thus, in economic terms, the trade-off between fuelwood and carbon sequestration is well in favor of fuelwood. However, it is likely that current fuelwood use levels are unsustainable, which will require action by the city authorities. This is one of the first studies to determine the value of fuelwood production from public urban green spaces. As such, the high values indicate that this omission needs to be rectified in future studies determining the value of provisioning ecosystem services provided by public urban green spaces, especially in Global South settings.

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