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THE INFLUENCE OF CHARCOAL PRODUCTION ON THE SAVANNAH WOODLAND DIVERSITY OF NYARAVUR SUB-COUNTY, NEBBI DISTRICT, UGANDA

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ABSTRACT

Charcoal remains a major cooking fuel and livelihood resource in Uganda, yet commercial production can intensify harvesting of mature trees, reduce species diversity, alter woodland structure and weaken ecosystem regeneration where production is poorly regulated. The influence of charcoal production on savannah woodland diversity in Uganda remain unassessed. The study adopted a descriptive and field-based ecological survey design supported by quantitative and qualitative approaches. Data was collected from charcoal producers, local leaders and key informants using questionnaires, interviews and structured field observations. Findings showed a clear relationship between charcoal production and woodland degradation. High charcoal production plots recorded lower species diversity, fewer woody species, lower stem density and more tree stumps than low and medium production plots. The area extent of harvested sites ranged from 0.07 ha to 0.80 ha, with an average of 0.30 ha. Mbaro West and Angal Lower produced the highest annual number of bags, while Angal Upper recorded the highest estimated woodland depletion, at 94.96 ha per month, 1,139.54 ha per year and 20,511.72 ha over ten years. Overall, commercial charcoal production was estimated to deplete 1,607.16 ha of woodland annually and 28,928.88 ha over the last ten years across the three parishes. Thus, charcoal production has a significant negative influence on savannah woodland diversity through reduced tree density, selective loss of preferred species, increased stump occurrence and progressive woodland depletion. It recommends adoption of regulated harvesting, restoration of indigenous tree species, community-based woodland management and livelihood-sensitive clean energy transition measures.

Keywords: Charcoal production, Savannah woodland diversity, Woodland depletion, Tree density, Species diversity

INTRODUCTION

Charcoal remains an important household energy source across sub-Saharan Africa because it is relatively affordable, transportable, familiar to users and compatible with many cooking practices. According to Rose, et al., (2022), it was estimated that about 195 million people in sub-Saharan Africa depend on charcoal as their primary cooking fuel, while others use it as a secondary fuel. In Uganda, biomass continues to dominate household cooking energy, and charcoal is especially important in urban and peri-urban areas where households prefer it because it is cleaner and easier to transport than firewood (Bamwesigye et al., 2020; Ogwok, et al., 2022). This dependence makes charcoal an energy-security issue, a livelihood issue and an environmental governance issue at the same time.

The ecological concern is that charcoal production is commonly linked to selective harvesting of mature trees, disturbance of woodland structure and gradual degradation of forest and savannah ecosystems. Chidumayo and Gumbo (2013) observe that charcoal production can affect species composition, woodland structure and ecosystem functioning when harvesting exceeds regeneration. More recent studies in Ghana, Mozambique, Angola and the Democratic Republic of Congo similarly show that charcoal production can reduce tree cover, create charcoal scars, change open forest into shrubland, delay regeneration and weaken ecosystem services (Arko, et al., 2024; Kissanga, et al., 2024; Mabutana, Molander, & Klintenberg, 2025). These findings are relevant to Uganda because the country also faces high biomass dependence and continuing woodland pressure from charcoal demand (NEMA, 2024; Okillong, 2025).

The issue is, however, not one-sided. Charcoal production supports rural livelihoods, especially in places where households have limited formal employment, poor access to markets and few alternative income sources. Kiruki, et al., (2020) show that charcoal income may not fully lift households out of poverty but can reduce the poverty gap and provide emergency income. According to Wekesa, et al., (2023) similarly caution that restrictions on charcoal production can create livelihood shocks when alternative livelihoods and affordable clean energy options are weak. Therefore, this article treats charcoal production in Nyaravur Sub-County as both an ecological pressure and a livelihood activity that requires balanced, evidence-based and context-sensitive interpretation. Nyaravur Sub-County in Nebbi District lies within Uganda's West Nile sub-region, an area where savannah woodland resources support household energy needs, charcoal production, timber extraction, grazing, agriculture and other livelihood activities. This study examines the extent of harvested woodland sites, the rate of charcoal production and the estimated depletion of woodland due to commercial charcoal production. This ought to provide local evidence on how charcoal production affects tree density, species diversity, vegetation structure and long-term woodland sustainability in a rural Ugandan setting.

Theoretical Framework

The article is guided by resource dependence theory and ecological disturbance theory. Resource dependence theory explains how communities depend on woodland resources for fuel, income, construction materials and other livelihood needs. In rural charcoal-producing areas, producers often harvest woodland trees because charcoal provides a quick cash return in a context of limited livelihood alternatives (Kiruki et al., 2020; Wekesa et al., 2023). This theory is useful because it explains why charcoal production continues even when communities understand that tree cutting can degrade the environment. It also explains why environmental regulation must be linked to livelihood alternatives, producer organisation and affordable energy transition rather than enforcement alone (Branch, Phillips, & Agyei, 2023; Schure, et al., 2019).

Ecological disturbance theory is also relevant because charcoal production is a form of anthropogenic disturbance that removes biomass, changes species composition and modifies woodland structure. In savannah woodland ecosystems, tree removal may reduce mature stems, alter canopy structure, expose soil, weaken natural regeneration and change habitat quality for plants and animals (Chidumayo & Gumbo, 2013; Kissanga et al., 2024; Nghonda et al., 2024). Charcoal production may not always produce immediate complete deforestation; it often begins as selective harvesting of preferred hardwood species. However, when selective harvesting is repeated and poorly regulated, woodland degradation can become progressive and cumulative (Mabutana et al., 2025; Sedano et al., 2021). The two theories therefore help explain the Nyaravur findings: charcoal production is driven by livelihood needs but produces ecological disturbance when harvesting exceeds the recovery capacity of woodland vegetation.

Review of Related Literature

Charcoal production is closely connected to Africa's energy transition challenge. Although global and national policies increasingly promote clean cooking, many households continue using charcoal because electricity, LPG and improved cooking systems remain unaffordable, unreliable or culturally unfamiliar in many communities (Elasu, et al., 2025; Ogwok et al., 2022). Okillong (2025) notes that charcoal production and consumption in Uganda have increased substantially over time, while Uganda's Energy Transition Plan estimates forest loss connected to wood fuels and continued biomass dependence. NEMA (2024) also reports that charcoal production from forests is often not effectively regulated and contributes to forest degradation, deforestation, greenhouse gas emissions and climate change. This literature shows that the pressure observed in Nyaravur Sub-County is part of a wider national problem driven by urban demand, rural supply and slow clean-cooking adoption.

Woodland diversity refers to the variety, abundance and structure of woody species, together with the capacity of the ecosystem to regenerate and sustain ecological functions. Charcoal production can influence diversity through selective removal of preferred tree species, reduction of mature stems, accumulation of stumps, soil disturbance and changes in the balance between saplings, poles and mature trees (Chidumayo & Gumbo, 2013; Kissanga et al., 2024). Arko et al. (2024) found extensive charcoal scars and large-scale tree depletion in Ghana's Afram Plains, showing that low-efficiency production and indiscriminate felling of mature trees can leave woodland landscapes degraded. In southern Mozambique, Mabutana et al. (2025) found that charcoal production contributed to a reduction in open forest and increased shrubland, indicating a shift in land cover and vegetation structure. In the Democratic Republic of Congo, Nghonda et al. (2024) demonstrates that anthropogenic pressure can reduce regeneration capacity and affect woodland recovery

Charcoal producers often prefer hardwood species because they produce charcoal with high heat output, long burning duration and better market acceptance. This preference creates selective pressure on particular tree species, especially mature individuals with suitable stem diameter and wood density (Chidumayo & Gumbo, 2013; Mabutana et al., 2025). Selective harvesting may initially appear less destructive than complete clearing because not all trees are removed at once. However, repeated removal of the same preferred species can gradually change species composition, reduce seed sources, lower regeneration potential and push producers towards less preferred species when high-quality species become scarce (Kissanga et al., 2024; Sedano et al., 2021). In Nyaravur Sub-County, this concern is strengthened by field evidence showing that stumps were recorded across many plots and that high charcoal production plots had lower woody species numbers and lower stem density than low and medium production plots.

Materials and Methods

The study adopted a descriptive and field-based ecological survey design. This design was suitable because it enabled the researcher to examine charcoal production practices and visible ecological conditions within savannah woodland sites at a specific point in time. The study used both quantitative approaches. Quantitative data captured the extent of woodland harvesting, tree density, stump occurrence, production rates and estimated depletion, while qualitative data from interviews and field observations helped explain the meanings and contextual realities behind the observed patterns (Creswell & Creswell, 2018; Leavy, 2022).

The study was conducted in Nyaravur Sub-County, Nebbi District, within Uganda's West Nile sub-region. The wider sub-county comprises Mbaro East, Mbaro West, Angal Lower, Angal Upper and Pamora Lower, but the field study focused on Mbaro West, Angal Lower and Angal Upper because they were active charcoal-producing parishes with savannah woodland resources. The study population included charcoal producers, local leaders and key informants from district, sub-county and parish structures. A total of 312 respondents were targeted, including charcoal producers and local governance actors, while the actual response comprised 219 questionnaire responses and 17 interviews.

Data were collected using questionnaires, interviews and structured observation. Questionnaires were administered to charcoal producers to gather information on production rate, woodland use and charcoal-related practices. Interviews with local leaders and key informants provided information on regulation, production trends, and woodland depletion and conservation concerns. Structured observation was used to record visible woodland conditions such as harvested sites, stumps, vegetation structure and active or abandoned charcoal production sites. Quantitative data were analysed using descriptive statistics, including frequencies, means and percentages, while qualitative data were analysed thematically to identify recurring explanations related to charcoal production and woodland diversity (Braun & Clarke, 2021). Ethical considerations included informed consent, confidentiality, anonymity and respect for local administrative procedures.

Results

The results are presented around three areas: ecological characteristics of woodland plots under different levels of charcoal production, parish-level charcoal production rates, and estimated woodland depletion due to commercial charcoal production. Together, these findings show how charcoal production influences species diversity, tree density, stump occurrence and spatial depletion of savannah woodland resources in Nyaravur Sub-County.

Ecological Characteristics of Woodland Plots by Charcoal Production Intensity

Field observations showed that woodland plots differed according to charcoal production intensity. The entire Nyaravur woodland recorded an average Shannon-Wiener diversity index of 1.48, an average of 6.3 woody species per 0.1 ha plot, 264 stems per hectare and 3.1 stumps per 0.1 ha plot. However, the intensity-specific results showed that high charcoal production plots had the lowest ecological condition among the production categories. As shown in Table 1, high charcoal production plots recorded a Shannon-Wiener index of 1.33, only 5 woody species per 0.1 ha plot, 140 stems per hectare and 14 stumps per 0.1 ha plot. This pattern indicates that intensive charcoal production is associated with lower tree density and higher evidence of tree cutting.

Table 1: Ecological characteristics of woodland plots under charcoal production intensity

Charcoal production intensity	No. of 0.1 ha plots	Shannon-Wiener index	Woody species/0.1 ha plot	Stem density/ha	Mean stumps/0.1 ha plot
No charcoal production	28	1.36	5.8 (2.4)	250 (126)	0
Low charcoal production	22	1.65	7.5 (1.96)	337 (134)	2.6 (3.7)
Medium charcoal production	14	1.63	7.2 (1.4)	270 (89)	5.5 (3.0)
High charcoal production	7	1.33	5.0 (1.8)	140 (59)	14 (6.0)

Source: Field data, March 2026

Results in Table 1 shows that low and medium charcoal production plots still had relatively higher woody species richness and stem density than high production plots. Low charcoal production plots recorded 7.5 woody species per 0.1 ha plot and 337 stems per hectare, while medium production plots recorded 7.2 woody species and 270 stems per hectare. In contrast, high production plots recorded fewer woody species and much lower stem density. The sharp rise in mean stumps from 2.6 in low production plots to 14 in high production plots strongly suggests increased tree harvesting pressure. These findings show that charcoal production does not simply remove individual trees; it also changes the structure and recovery capacity of the woodland.

Area Extent of Woodland Trees Harvested for Charcoal Production

The study found that the area extent of harvested sites varied from 0.07 ha to 0.80 ha, with an average harvested area of 0.30 ha across the observed sites. Larger harvested areas were recorded in the Acwera forest zone than in the Penji forest zone. The relationship between area extent and number of trees harvested was strong in the observed sites, with $r^2 = 0.7505$ in one forest zone and $r^2 = 0.6342$ in another. This means that the number of trees removed and the size of the harvested area were important indicators of woodland degradation. In some sites, many trees were harvested from relatively small areas, indicating concentrated harvesting, while in others the harvested trees were more scattered across larger areas. Both patterns matter because concentrated harvesting can create localized woodland gaps, while scattered harvesting can spread degradation over a wider landscape.

Rate of Charcoal Production by Parish

The rate of charcoal production differed across Mbaro West, Angal Lower and Angal Upper. Mbaro West and Angal Lower recorded the highest annual number of charcoal bags, while Angal Upper recorded fewer bags. Table 2 summarizes parish-level production indicators.

Table 2: Parish-level charcoal production indicators in Nyaravur Sub-County

Parish	Land area (km²)	Population density/km²	Villages	Tree density for production	Bags/household (mean +/- SE)	Bags/parish/year
Mbaro West	120	40	11	273 +/- 12	85 +/- 12	935
Angal Lower	63	35	10	550 +/- 116	90 +/- 33	960
Angal Upper	70	54	12	267 +/- 87	20 +/- 4	596

Source: Field data, March 2026.

The findings in Table 2 show that Angal Lower produced the highest number of bags per year (960), followed by Mbaro West (935) and Angal Upper (596). The higher production in Angal Lower and Mbaro West suggests more active charcoal harvesting pressure. However, the relationship between production and depletion was not uniform across parishes because depletion also depends on the area harvested, tree density, type of woodland, distance to production sites and availability of preferred tree species. This explains why Angal Upper, despite having a lower number of bags per year, recorded the highest estimated depletion per bag and per year in Table 3.

Estimated Depletion of Woodland Due to Commercial Charcoal Production

The study estimated woodland depletion due to commercial charcoal production across the three parishes. The findings show that commercial charcoal production is responsible for substantial woodland loss over time. Table 3 presents the estimated depletion indicators.

Table 3: Estimated woodland depletion due to commercial charcoal production

Measured variable	Mbaro West	Angal Lower	Angal Upper	Average/Total
Average land area (ha)	5687.7	4567.3	4479.6	4911.43
Depleted area due to charcoal production (ha/bag)	0.014	0.007	0.017	0.010
Depleted area due to charcoal production (ha/month)	55.94	10.39	94.96	133.93
Depleted area due to charcoal production (ha/year)	679.28	124.68	1139.54	1607.16
Depleted area due to charcoal production (ha/10 years)	12083.04	2244.24	20511.72	28928.88

Source: Field data, March 2026.

The results in Table 3 show that the average land area under depletion pressure was 4,911.43 ha. Monthly production was estimated to deplete 133.93 ha across the three parishes, while annual production was estimated to deplete 1,607.16 ha. Over ten years, the estimated woodland depletion reached 28,928.88 ha. Parish-level comparison shows that Angal Upper had the highest estimated depletion at 0.017 ha per bag, 94.96 ha per month, 1,139.54 ha per year and 20,511.72 ha over ten years. Mbaro West followed with 0.014 ha per bag, 55.94 ha per month, 679.28 ha per year and 12,083.04 ha over ten years. Angal Lower had the lowest estimated depletion, at 0.007 ha per bag, 10.39 ha per month, 124.68 ha per year and 2,244.24 ha over ten years.

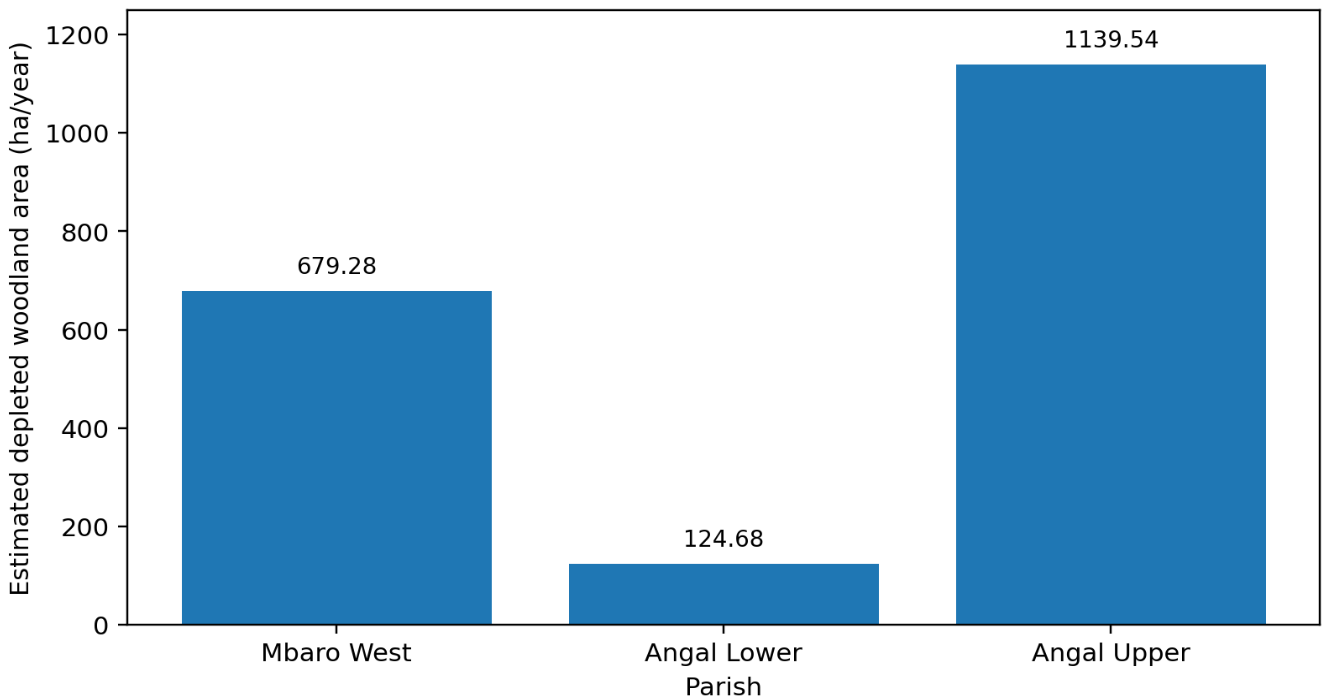

Figure 1: Estimated annual woodland depletion due to commercial charcoal production
Source: Field data, March 2026.

Figure 1 reinforces the parish-level differences in depletion. Angal Upper recorded the largest estimated annual depletion, suggesting that woodland harvesting intensity and available tree distribution may be more ecologically damaging there than the number of bags alone indicates. The results therefore show that charcoal production affects savannah woodland diversity through both quantity of production and spatial pattern of harvesting.

Discussions

The findings demonstrate that charcoal production has a significant negative influence on savannah woodland diversity in Nyaravur Sub-County. The clearest evidence is observed in the comparison of charcoal production intensity categories. High charcoal production plots had the lowest Shannon-Wiener diversity index, the lowest number of woody species, the lowest stem density and the highest number of stumps. This pattern confirms that intensive charcoal production reduces tree abundance and alters woodland structure. The findings agree with Chidumayo and Gumbo (2013), who argued that charcoal production can change species composition and ecosystem functioning in tropical woodlands when harvesting is repeated and poorly managed. They also agree with Arko et al. (2024), who found that extensive charcoal production in Ghana was associated with the depletion of many trees and visible degradation scars across the landscape.

The lower stem density recorded in high charcoal production plots is particularly important. Stem density is a useful indicator of woodland condition because it reflects the number of trees available to maintain canopy structure, seed supply, habitat functions and future biomass. When stem density falls from 337 stems per hectare in low production plots to 140 stems per hectare in high production plots, the implication is not only loss of trees but also weakening of ecological continuity. This supports the finding by Nghonda et al. (2024) that anthropogenic pressure can limit regeneration capacity and affect floristic diversity in Miombo woodland systems. It also aligns with Kissanga et al. (2024), who show that selective cutting for charcoal can influence woodland recovery dynamics and change the balance between recent, intermediate and mature fallows.

The high number of stumps in high charcoal production plots provides direct field evidence of harvesting pressure. Stumps are important because they show where trees have been removed, even when charcoal bags have already been transported away. The rise from zero stumps in no-charcoal-production plots to 14 stumps per 0.1 ha plot in high production plots demonstrates a strong relationship between charcoal production and tree removal. This evidence is consistent with Mabutana et al. (2025), who found that charcoal production in southern Mozambique led to land-cover changes and was associated with reduced open forest and increased shrubland. In Nyaravur Sub-County, the observed stumps and reduced stem density suggest that continued harvesting may progressively shift woodland structure from mature tree cover towards degraded, open or shrub-dominated formations if restoration is not strengthened.

The findings also show that production rates alone do not fully explain ecological depletion. Angal Lower recorded the highest annual number of bags, but Angal Upper recorded the highest estimated depletion per bag, per month, per year and over ten years. This means that the ecological cost of charcoal production depends on more than the number of bags produced. It is shaped by tree density, tree size, species preference, and distance between harvesting sites, woodland condition and the efficiency of kilns used. This interpretation is supported by Sedano et al. (2021), who argue that the link between forest degradation and urban energy demand can be spatially uneven and requires landscape-level monitoring. It also supports Sakala, Olin and Santos (2023), who demonstrate that charcoal production can affect carbon cycling differently across African biomes depending on vegetation type and recovery capacity.

The estimated depletion of 1,607.16 ha per year and 28,928.88 ha over ten years across the three parishes is environmentally alarming. Although these figures are local estimates, they show the direction of pressure on savannah woodland resources if production continues without stronger regulation and restoration. NEMA (2024) reports that charcoal production from forests in Uganda is often not effectively regulated and contributes to forest degradation, deforestation and greenhouse gas emissions. Okillong (2025) further links Uganda's charcoal demand to severe deforestation and notes that clean energy transition remains difficult because charcoal is deeply embedded in household energy and livelihoods. The Nyaravur findings therefore provide local evidence of a national challenge: charcoal is economically useful but ecologically costly when extraction is not matched with regeneration and sustainable wood supply.

The findings should also be interpreted with human sensitivity. Charcoal producers in Nyaravur Sub-County are not simply destroying woodland for no reason; many depend on charcoal for income, especially where alternative livelihoods are limited. Kiruki et al. (2020) show that charcoal production can reduce poverty severity among rural households, while Wekesa et al. (2023) warn that bans can harm value-chain actors if introduced without alternatives. Therefore, recommendations should avoid punitive enforcement alone. A better approach is to combine improved kiln technologies, regulated harvesting, producer training, woodlot development, assisted natural regeneration and gradual clean-cooking transition. This agrees with Schure et al. (2019), who argue that sustainable charcoal solutions must go beyond kilns to include governance, producer organisation, market incentives and sustainable resource management.

Study Limitations

Although the study used field observations, questionnaires and interviews, some data depended on self-reporting by charcoal producers and local leaders, which may be affected by recall limitations or fear of regulation. The depletion estimates are useful for showing the scale and direction of woodland pressure, but future studies should strengthen this evidence using remote sensing, repeated vegetation inventories, biomass measurements, species-specific regeneration assessments and carbon-stock analysis.

Conclusions and recommendations

The article concludes that charcoal production has a clear negative influence on savannah woodland diversity in

Nyaravur Sub-County. High charcoal production areas recorded lower species diversity, fewer woody species, lower stem density and more tree stumps, indicating that intensive harvesting weakens woodland structure and reduces ecological resilience. The area extent of harvested woodland sites and the strong relationship between number of trees cut and harvested area further confirm that charcoal production contributes to visible degradation. Parish-level estimates show that commercial charcoal production is depleting substantial woodland area annually and may cause severe long-term loss if current practices continue. The findings therefore demonstrate that charcoal production in Nyaravur Sub-County is not merely an energy or livelihood activity; it is also a major ecological pressure affecting tree species composition, regeneration potential, vegetation structure and long-term savannah woodland sustainability.

The sturdy recommends that, charcoal producers should be organized into local producer groups and trained in improved kiln technologies, selective harvesting limits, stump protection, coppice management and safe production practices. Tree planting and assisted natural regeneration should focus on indigenous species preferred for charcoal production, while community woodlots should be promoted to reduce pressure on natural savannah woodland. Clean energy transition should be gradual, affordable and livelihood-sensitive by expanding improved cook stoves, LPG access, electricity reliability and alternative income activities such as agroforestry, beekeeping, and tree nurseries and sustainable fuel wood plantations. Enforcement should target destructive commercial harvesting and illegal trade while avoiding blanket actions that punish poor rural producers without providing realistic alternatives. Further research should also examine the effectiveness of improved kilns, the economics of community woodlots, the role of women in charcoal value chains and the social impacts of charcoal regulation in West Nile.

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