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Environmental implications of charcoal production in Kudai, Dutse Local Government Area, Jigawa State, Nigeria

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ABSTRACT

Charcoal production is an important energy and livelihood activity in semi-arid communities, yet the removal of woody biomass can weaken vegetation structure and ecosystem resilience. This study examined the environmental implications of charcoal production in Kudai, Dutse Local Government Area, Jigawa State, Nigeria. A mixed-methods, cross-sectional design combined field observation, a comparative vegetation-density survey, a structured questionnaire administered to 110 respondents (multi-stage purposive and stratified random sampling) and semi-structured interviews with 10 key informants. Tree density was used as the principal field indicator of vegetation condition, the principal field indicator of vegetation condition, was counted in five 20 m × 20 m plots (equals 400 m^2) in heavily exploited locations and five in relatively undisturbed locations. Descriptive statistics and an independent-samples t-test (SPSS version 26) were applied to the quantitative data, and interviews were analysed thematically. Mean tree density was 3.40 ± 1.34 trees per plot (about 85 trees ha^{-1}) in heavily exploited sites and 11.20 ± 1.48 trees per plot (about 280 trees ha^{-1}) in relatively undisturbed sites; the difference was statistically significant, $t(8) = -8.74$, $p < 0.001$. Residents most often reported poverty (100%), income needs (95.5%) and household energy needs (76.4%) as reasons for charcoal production. Support for restrictions was conditional on alternative livelihoods for 54.5% of respondents, and 62.7% would stop producing charcoal if viable alternatives were available. Because the comparison rests on ten purposively located plots in a single community, the results indicate a strong association rather than a complete causal estimate. Conservation measures are likely to be more credible and durable when paired with livelihood diversification, affordable clean energy, community-based restoration and enforceable harvesting controls.

Keywords: charcoal production; tree density; vegetation condition; biophysical environment; afforestation; livelihood; Kudai; Jigawa State

Introduction

Access to household energy is a basic requirement, but in many developing settings that requirement is still met largely through biomass fuels. More than 2 billion people in the developing world rely primarily on fuelwood for domestic energy (Rotowa et al., 2019). In Africa, roughly nine-tenths of the wood removed from forests is used as fuel, and in sub-Saharan Africa charcoal is the main urban cooking fuel in at least 21 countries, with demand growing by about 4% a year since 2000 (Sedano et al., 2022). In Nigeria, charcoal and fuelwood remain widely used for domestic cooking, particularly where cleaner alternatives are costly or difficult to obtain (Ogundele et al., 2011; Zaku et al., 2013), and population

growth has been identified as a major force behind forest loss (Oyetunji et al., 2020). This creates a difficult environmental trade-off: the same resource that provides immediate energy and income is also the resource on which future ecosystem services depend.

Kudai presents this tension at the community scale. The settlement lies in the semi-arid northern part of Nigeria, within Dutse Local Government Area (LGA). Its sandy soils, seasonal climate and savanna vegetation mean that the removal of woody cover can have consequences beyond the loss of individual trees: once vegetation is removed, the protective functions of canopy and roots are weakened, exposing the soil and reducing the landscape's capacity for natural recovery (Chidumayo & Gumbo, 2013).

The research problem is therefore not simply that charcoal is produced. Production becomes environmentally unsustainable when tree harvesting is faster than regeneration and when households have few practical alternatives (Chidumayo & Gumbo, 2013; Zulu & Richardson, 2013). Remote-sensing studies in Mozambique and Zambia show that charcoal-driven degradation can proceed as a process distinct from agricultural clearing and can spread progressively further from urban centres (Ahrends et al., 2010; Sedano et al., 2016, 2022). Comparable plot-level evidence from Dutse's semi-arid communities, paired with residents' own accounts of why trees are cut, was not found in the literature reviewed for this paper.

Research problem

The central problem is the absence of sufficiently localised evidence linking charcoal production practices with measurable vegetation differences and community decision-making in Kudai. Generalised policies may fail when they do not address the reasons people harvest trees, the species most exposed to pressure, or the conditions under which residents would support restrictions.

A note on terminology is necessary. In this paper, "vegetation condition" refers to the structure and density of woody cover. Tree density (trees per 400 m^2 plot and trees per hectare) was the only quantitative vegetation measure and is therefore used as the principal field indicator of vegetation condition. Canopy condition, stumps, bare ground, erosion and regeneration were recorded qualitatively on a field checklist. Vegetation cover in the sense of percentage canopy or ground cover was not measured.

Aim and objectives of the study

The study aimed to assess the environmental implications of charcoal production in Kudai, Dutse Local Government Area, Jigawa State, with emphasis on vegetation condition. It pursued three objectives:

i. Assess the effect of charcoal production on vegetation condition in Kudai, using tree density as the principal field indicator.
ii. Examine community perceptions of, and field evidence for, afforestation and restoration practices in Kudai.
iii. Identify the socio-economic factors that residents report as motivating charcoal production in Kudai.

Research questions

In line with the purpose of the study, the following research questions were raised:

i. How does charcoal production affect vegetation condition (tree density) in Kudai?
ii. How do residents of Kudai perceive afforestation practices in their community?
iii. What socio-economic factors do residents report as motivating charcoal production?

Conceptual and theoretical framework

Charcoal production and environmental change

Charcoal is produced by heating woody biomass under restricted oxygen through carbonisation or pyrolysis (Saad & Bugaje, 2016). Traditional earth-mound and earth-pit kilns are common low-technology approaches. Their environmental significance begins before the kiln: trees must first be harvested, transported and prepared. Where harvesting exceeds regeneration, repeated extraction gradually changes vegetation structure and exposes soil (Chidumayo & Gumbo, 2013).

Biophysical pathway

The conceptual logic of the study can be expressed as a simple chain: charcoal production → tree felling and carbonisation → reduced tree density and regeneration → soil exposure and erosion → wider land and ecosystem degradation. Vegetation is central because trees stabilise soil, provide habitat, regulate microclimatic conditions and store carbon (Abba et al., 2021; Chidumayo & Gumbo, 2013). Their removal can therefore produce effects that extend beyond the immediate production site. Land degradation nevertheless has multiple interacting pathways (Prăvălie, 2021), which is why the present study treats its tree-density contrast as evidence of association and not as proof of a single cause.

Theoretical framework

Human–Environment Interaction Theory provides the primary lens. It explains why communities depend on natural resources and how human activities subsequently modify environmental conditions. In Kudai, the need for income and household energy encourages forest-resource use, while the resulting tree loss changes vegetation and land conditions.

Political Ecology of Resource Use adds a structural perspective. It draws attention to market demand, unequal access to resources, institutional capacity and the distribution of environmental costs and economic benefits. This is important because charcoal production may be a local activity while being sustained by wider urban energy demand.

The Theory of Environmental Perception complements these perspectives by explaining why people may acknowledge environmental degradation yet make decisions that continue to place pressure on natural resources. Perception is shaped by experience, livelihood priorities, knowledge, values and trust in environmental programmes. The three theories are used to interpret the findings; they are not tested formally.

Review of related literature

Studies in Nigeria, Ghana, Kenya and elsewhere consistently associate charcoal production with deforestation, soil degradation and livelihood dependence. Adebayo et al. (2019) found that charcoal production was a significant driver of forest depletion in selected agrarian communities of Oyo State, Nigeria. Among the 160 charcoal producers studied, 73.8% perceived charcoal production as a serious environmental threat, and a chi-square test showed a significant relationship ($p < 0.05$) between education level and perceived effects on deforestation. *Vitellaria paradoxa*, *Anogeissus leiocarpus* and *Bridelia ferruginea* were among the most commonly exploited species, and the authors recommended afforestation, reforestation and environmental awareness initiatives.

Eniola and Odebode (2018) surveyed charcoal producers in the rainforest and Guinea savanna zones of Nigeria. Most respondents perceived that charcoal production leads to erosion (62.7%), reduces the number of trees available for future use (62.4%) and affects the air environment (54.1%), and perceived effects differed significantly between the two zones. Absolom (2014) reported that unsustainable commercial charcoal production in Narok-South Sub-County, Kenya, accelerated deforestation and created wider environmental and socio-economic concerns, including potential effects on crop yields, tourism and poverty. Salifu (2013) found notable differences between charcoal-production and non-production sites in soil texture, hydraulic conductivity and selected soil nutrients in the Central Gonja District of northern Ghana; remote-sensing analysis also showed that intact Guinea savanna woodland declined from about 22,662 ha to 11,739 ha between 1990 and 2010.

Rotowa et al. (2019) reported that unregulated charcoal production was contributing to pressure on Nigeria's forest estate and recommended stronger forest management and regulatory control together with afforestation and participatory forest management. Olasimbo and Johnson (2018) found that charcoal production in the Oke-Ogun area of Oyo State was strongly linked to livelihood needs, was male-dominated, and faced declining tree availability, wildfire, government interference and transport difficulties. In northern Nigeria, Chomini et al. (2022) studied fuelwood and charcoal producers in Toro LGA, Bauchi State, and identified poverty as the main driver of resource destruction; 88% of producers cut live trees, a harvesting method the authors judged to inhibit replenishment, and the apparent collapse of traditional governance was correlated with fuelwood exploitation.

More recent evidence on charcoal value chains, land degradation and forest governance in Africa sharpens three points. First, charcoal is an important source of rural income, but whether it offers a pathway out of poverty depends on how production is organised and governed (Schure et al., 2014; Zulu & Richardson, 2013). Second, land tenure and labour relations shape the environmental footprint of production (Pelletier et al., 2021), and widely held misconceptions about charcoal can distort policy (Mwampamba et al., 2013). Third, remote sensing has shown that charcoal-related degradation can rival agricultural deforestation in magnitude: in Tete, Mozambique, degradation linked to charcoal was of the same order as deforestation (Sedano et al., 2016), and in three Zambian forest reserves kiln scars were found in more than 85% of sampled sites, with a 74.2% reduction in tree cover at production sites and production moving from about 190 km to about 350 km from Lusaka between 2010 and 2020 (Sedano et al., 2022). Similar waves of sequential

degradation radiating from an African city had

earlier been documented in Tanzania (Ahrends et al., 2010).

On the demand side, charcoal and firewood persist in Nigerian households because they are cheaper and more accessible than alternatives (Zaku et al., 2013). Global estimates indicate that progress towards clean cooking has been slowest in sub-Saharan Africa (Stoner et al., 2021), and the carbon footprint of traditional woodfuels remains substantial (Bailis et al., 2015), so transitions away from charcoal are likely to be gradual. The studies reviewed here are drawn mainly from southern Nigeria, Ghana, Kenya and southern Africa. The present study contributes plot-level evidence from a semi-arid community near Dutse, paired with residents' accounts of why charcoal is produced.

Materials and methods

Study area

The study was conducted in Kudai community, Dutse LGA, Jigawa State, north-western Nigeria (Figure 1). The community lies at approximately 11°37'59" N and 9°20'59" E, within a semi-arid Sudan savanna setting close to Dutse, the state capital.

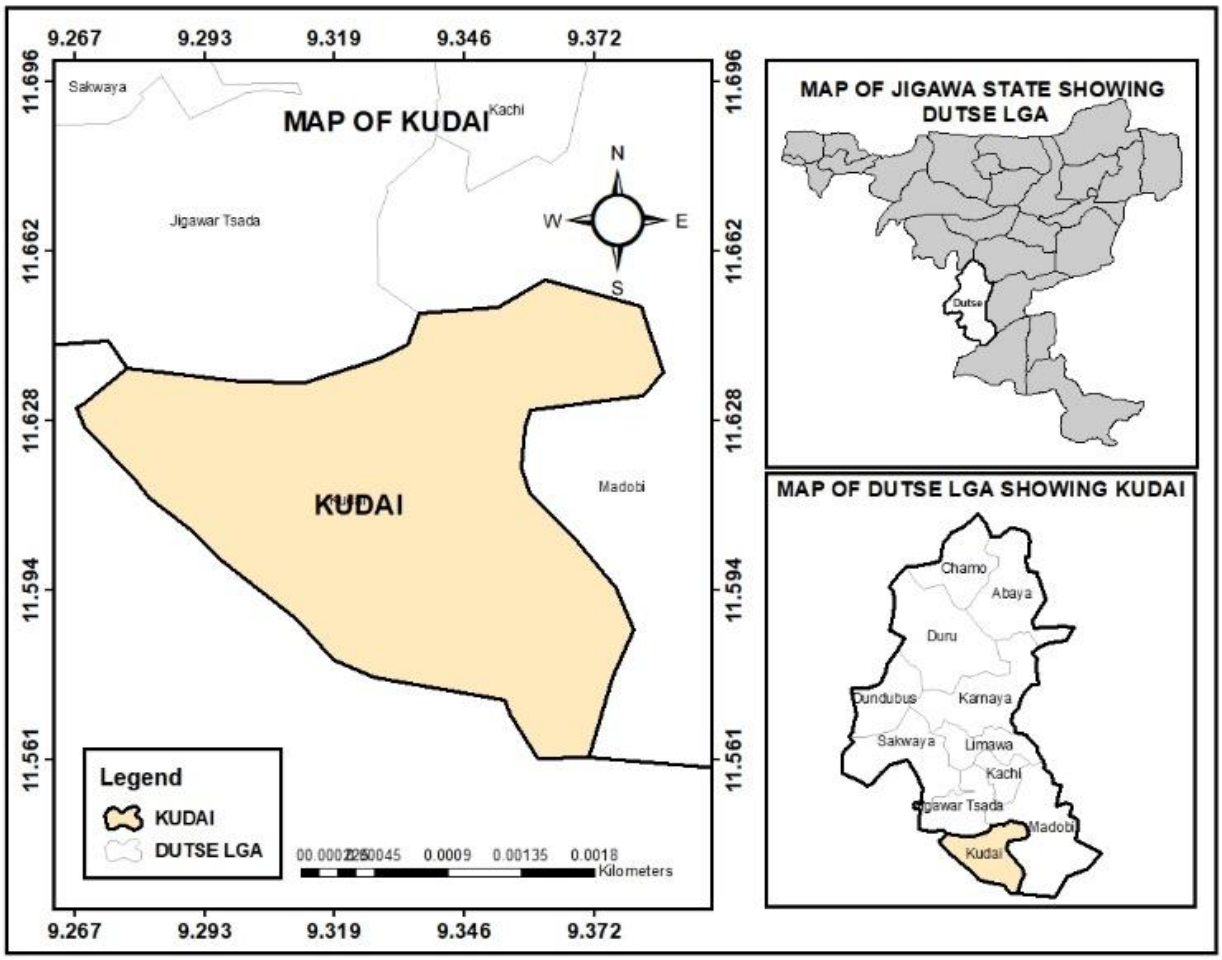


Figure 1: Map showing Kudai and the wards of Dutse LGA, Jigawa State

Source: Authors Contributor, 2026.

. Table 1 summarises the characteristics of the study area that are relevant to interpreting the results.

Table 1: Characteristics of the study area

Attribute	Description
Location	Kudai community, Dutse LGA, Jigawa State, north-western Nigeria; about 11°37′59″ N, 9°20′59″ E, close to the state capital (Figure 1).
Administrative and cultural setting	Dutse LGA contains the Jigawa State capital; Jigawa State borders Kano (west), Bauchi and Yobe (east) and Katsina (north) (Lawal et al., 2018). The community is predominantly Hausa–Fulani, with farming and Islamic institutions central to social life.
Land area	Dutse LGA covers about 1,089 km^2. A land-area figure specific to Kudai was not available.
Population	Dutse LGA recorded 251,135 people in the 2006 census, with a 2022 projection of about 431,800 and an estimated 52,982 households as reported by the National Population Commission. Figures specific to Kudai were not available and the LGA figures are given as context.
Climate and temperature	Semi-arid tropical climate with distinct wet and dry seasons. Annual average temperatures range from about 12 °C to 39 °C, with rare extremes of about 9 °C and 42 °C (Ibrahim et al., 2023).
Rainfall pattern	Relatively low and strongly seasonal. Quantitative rainfall records for Kudai were not obtained in this study.
Relief and drainage	Gently undulating, rocky terrain with granite and gneiss outcrops, sandy plains and seasonal drainage; erosion and flooding occur during intense rainfall (Ibrahim et al., 2023).
Soils	Predominantly sandy, weathered and of low fertility and organic-matter content, with shallow stony soils around rock outcrops. Such soils are highly susceptible to wind and water erosion, which limits recovery once vegetation is removed.
Dominant vegetation	Sudan savanna with trees such as *Azadirachta indica*, *Parkia biglobosa* and *Hyphaene thebaica*, shrubs such as *Guiera senegalensis*, and cultivated millet and sorghum (Abdullahi et al., 2017). Vegetation is under increasing pressure from desertification and human activity (Azare et al., 2020).
Land use and livelihoods	Residential, commercial and agricultural land use. Farming (millet, sorghum, groundnut, sesame, hibiscus, vegetables) and livestock rearing are the main livelihoods, supplemented by petty trade, small-scale processing and artisanship (Lawal et al., 2018).
Energy use and charcoal-production context	Firewood and charcoal are the main household fuels. Charcoal provides income for people involved in harvesting, processing and distribution, and production uses traditional earth-mound and earth-pit kilns. The field survey recorded three active and four abandoned production sites, and ash deposits around abandoned kilns indicate repeated use of the same sites. A documented production history for Kudai was not available.
Accessibility	Kudai lies close to Dutse town. Access to some production sites is constrained by poor road networks and distance.
Reason for selecting Kudai	(a) Charcoal production is an active livelihood and fuelwood and charcoal are the main household fuels; (b) the community lies close to Dutse and therefore to urban charcoal demand; and (c) site-specific baseline data on the vegetation effects of charcoal production were lacking.

Source: Compiled from the sources cited and the authors' field survey, 2026.

Research design

A mixed-methods, cross-sectional field design was used, and data were collected between March and July 2026. The design combined direct observation, vegetation-density counts, a questionnaire survey and semi-structured key informant interviews, so that ecological measurements could be triangulated with local experience and socio-economic context. The study followed a positivist orientation for the biophysical measurements, with pragmatic elements that bring in local knowledge and perceptions. The design is descriptive and observational: it compares sites that already differ in charcoal-production intensity and does not manipulate or randomly assign exposure.

Sampling and data collection

Questionnaire survey

Target population and sampling frame. The target population comprised individuals and households in Kudai who are directly or indirectly involved in, or affected by, charcoal production, including producers, farmers, traders, community leaders and other residents. The sampling frame was a list of households in Kudai compiled from community records and local administrative registers. The survey was confined to a single settlement (Kudai), so no ward-level or multi-settlement allocation was used.

Sampling design. A multi-stage design combined purposive and stratified random sampling. Knowledgeable stakeholders, such as community leaders, charcoal producers and traders, were selected purposively because of their direct involvement in charcoal production. Community respondents were grouped into strata defined by occupation, age and sex, and respondents were then selected at random in proportion to the size of each stratum. Households in Kudai were first listed to form the sampling frame. The frame was divided into strata by occupation, age, and gender; Gender, age and occupation, each sum to 110 independently, so they read as three separate breakdowns rather than one cross-classified design. Naming occupation as the primary stratum, with age and gender recorded as secondary characteristics. 13 respondents were below 18, parental or guardian consent was obtained for respondents younger than 18 years. The resulting composition of the sample is shown in Table 2.

Sample size. The sample size was calculated with Cochran's formula for finite populations, $n_0 = Z^2 p(1 - p)/e^2$, using a 90% confidence level ($Z = 1.645$), a margin of error of 0.08 and an estimated proportion of 0.4. This gave $n_0 = 101.5$, or about 101. Applying the finite-population correction with $N = 52{,}982$ (the estimated number of households in Dutse LGA, used as an upper bound) left the sample at about 101. To allow for non-response and incomplete questionnaires, the sample was increased to 110 respondents.

Respondents and administration. Respondents were residents drawn from the household list and included producers, farmers, traders, civil servants, students and others (Table 2); they were not restricted to household heads or to producers, and the age distribution includes 13 respondents (11.8%) younger than 18 years. The study population consisted of residents, charcoal producers, farmers, traders and community leaders in Kudai who were directly or indirectly involved in, or affected by, charcoal production. The exclusions applied were at the level of study scope. Other settlements, laboratory analyses, GIS-based assessments and health impacts were left out. No respondent-level exclusion criteria were specified. The number of questionnaires distributed was not recorded separately. The planned sample size was 110, obtained from Cochran's formula, which gave an initial value of about 101. This was raised to 110 to allow a 5–10% margin for non-response and incomplete questionnaires. In Chapter 4, 110 respondents were analysed, alongside 10 key informants who took part in the interviews. 110 questionnaires were distributed and returned, the rate was 100%.

The structured questionnaire had six sections: (A) socio-demographic characteristics; (B) production practices, methods and motivations; (C) perceived biophysical impacts (Likert-

scale items); (D) afforestation awareness, participation, willingness and barriers; (E) socio-economic drivers, including income, employment, alternatives and energy sources; and (F) knowledge of regulations and support for management interventions. Questionnaires were administered face to face by the researcher and trained research assistants, who helped respondents with limited literacy and recorded their responses accurately.

Key informant interviews

Ten key informants were selected purposively for their knowledge of, and involvement in, charcoal production and forest use in Kudai: four charcoal producers, three farmers, two civil servants and one other resident. Informants were interviewed privately using semi-structured schedules covering awareness of afforestation, attitudes to tree planting, perceived benefits and barriers, poverty, unemployment, energy needs, policy enforcement and cultural practices. Interview responses were transcribed for analysis.

Vegetation-density assessment

Vegetation density was measured in 20 m × 20 m (400 m^2) plots, within which trees and stumps were counted. Five plots were located in heavily exploited areas, where charcoal production was active, and five in relatively undisturbed areas nearby where no charcoal production was taking place. Plots were located purposively, not randomly or systematically. Sites were classified in the field using the checklist indicators in Table 5: heavily exploited sites showed active or abandoned kilns, many stumps, sparse canopy and extensive bare ground, whereas relatively undisturbed sites had no kilns, very few stumps and denser canopy. The 10 plots were chosen within a category located on separate parcels and kiln sites Five plots per category were what time, cost and access allowed (Section 8, Limitations); the number was not set by a formal power calculation. The comparison is therefore treated as a site-level contrast that is sensitive to the choice of individual plots between active kiln sites areas where charcoal production is taking place regularly and the undisturbed areas where charcoal production is fully restricted, these cannot give a community-wide estimate. Canopy condition was judged by visual estimation and sites were documented photographically.

Field observation checklist

A checklist of 15 environmental indicators was used to record evidence of tree felling, stumps, felled logs, kilns, active and abandoned production sites, stored charcoal, canopy, bare land, ash deposits, land degradation, reforestation activity, awareness signboards and seedlings. Each indicator was recorded as present or absent, with counts where relevant (Table 5).

Data analysis

Data were processed and analysed with SPSS version 26, and Microsoft Excel (2019 or 365) was used for data organisation, tables and charts. vegetation counts per plot were summarised as means and standard deviations and converted to trees per hectare by multiplying plot values by 25 (one hectare equals 25 plots of 400 m^2). An independent-samples *t*-test (two-tailed, $\alpha = 0.05$) was used to test whether mean tree density differed between site categories.

Questionnaire responses were summarised as frequencies and percentages. Because sex, age group, education and occupation are categorical variables, means and standard deviations of numerically coded categories have no meaningful interpretation and are not reported. For the multiple-response item on reasons for producing charcoal, percentages were calculated on the 110 respondents and therefore do not sum to 100%.

Interview transcripts were coded, and codes were grouped into recurring themes and interpreted against the three objectives (Braun & Clarke, 2006). Interview material was used to explain and contextualise the measured data and not as a substitute for the ecological comparison. Findings from the three data sources were triangulated. The questionnaire data describe factors reported or perceived by residents as motivating charcoal production; they do not test statistical association with actual participation.

Ethical considerations

The study followed accepted ethical principles for research with human participants. (i) *Informed consent*: participants were told the purpose and procedures of the study before taking part; for those unable to read, the information was explained verbally in Hausa, and verbal consent was obtained in the presence of a neutral witness. Participants could withdraw at any time without penalty. (ii) *Confidentiality and anonymity*: names, telephone numbers and household locations were not recorded in the report; each respondent was given a unique code and results are presented in aggregate. (iii) *Non-incrimination*: because charcoal production may be restricted by regulation, the study avoided collecting exact forest locations, production volumes or operational networks, and responses were not shared with enforcement authorities. If illegal felling was observed, the researchers kept an observational role and recorded it only in generalised, non-identifiable terms. (iv) *Voluntary participation*: community leaders facilitated entry but could not compel participation, and interviews were held privately. (v) *Respect for local norms*, including greetings, dress and community protocols. (vi) *Data security*: hard copies were kept in secured storage, with access limited to the researchers and authorised supervisor; data were used only for academic purposes and are to be destroyed securely after completion. (vii) *Environmental responsibility*: field activities were conducted so as to avoid harming vegetation. A formal ethical clearance was not required for the study; parental or guardian consent was obtained for respondents younger than 18 years.

Results

Respondent profile

The respondent profile was diverse but male-dominated (Table 2). Males represented 67.3% of the 110 questionnaire respondents and females 32.7%. The largest age group was 36–45 years (25.5%), followed by respondents aged 46 years and above (24.5%). Tertiary-educated respondents accounted for 39.1% and 36.4% had secondary education. Students formed the largest occupational category (32.7%); civil servants accounted for 16.4%, farmers and traders 11.8% each, charcoal producers 6.4% and other occupations 20.9%. Only seven

respondents were charcoal producers, so the questionnaire captured community-wide perceptions and not only the views of active producers.

Table 2: Socio-demographic characteristics of questionnaire respondents (N = 110)

Variable	Category	Frequency (n)	Percentage (%)
Sex	Male	74	67.3
	Female	36	32.7
Age group (years)	Below 18	13	11.8
	18–25	22	20.0
	26–35	20	18.2
	36–45	28	25.5
	46 and above	27	24.5
Educational level	No formal education	19	17.3
	Primary	8	7.3
	Secondary	40	36.4
	Tertiary	43	39.1
Main occupation	Farmer	13	11.8
	Charcoal producer	7	6.4
	Trader	13	11.8
	Civil servant	18	16.4
	Student	36	32.7
	Others	23	20.9

Source: Questionnaire survey, 2026. Percentages are of N = 110 and may not sum to exactly 100.0 because of rounding.

Effect of charcoal production on vegetation condition

Tree density

Tree density, the principal quantitative indicator, differed markedly between site categories (Table 3). The five heavily exploited plots contained 4, 2, 5, 4 and 2 trees, a combined count of 17 and a mean of 3.40 trees per plot, equivalent to about 85 trees ha^{-1}. The five relatively undisturbed plots contained 11, 9, 13, 12 and 11 trees, a combined count of 56 and a mean of 11.20 trees per plot, equivalent to about 280 trees ha^{-1}.

Table 3: Tree density in heavily exploited and relatively undisturbed plots in Kudai (20 m × 20 m plots)

Site category	Plot counts (trees)	Plots	Total trees	Mean ± SD (trees per plot)	Mean (trees ha^{-1})	Interpretation
Heavily exploited	4, 2, 5, 4, 2	5	17	3.40 ± 1.34	≈ 85	Low density
Relatively undisturbed	11, 9, 13, 12, 11	5	56	11.20 ± 1.48	≈ 280	Higher density

Source: Field survey, 2026.

The independent-samples t-test showed that the difference was statistically significant (Table 4). The mean difference was 7.80 trees per plot, or about 195 trees ha^{-1}, so relatively undisturbed plots held about 3.3 times the tree density of heavily exploited plots, and heavily exploited plots held about 70% fewer trees. Calculated from the plot counts, the 95% confidence interval for the mean difference was 5.74 to 9.86 trees per plot (about 143 to 247 trees ha^{-1}), and the standardised effect size was very large (Cohen's $d \approx 5.5$). Applying Welch's correction for unequal variances leads to the same conclusion ($p < 0.001$).

Table 4: Independent-samples *t*-test of mean tree density between site categories

Comparison	Mean difference (trees per plot)	*t*	*df*	*p* (two-tailed)
Relatively undisturbed vs heavily exploited	7.80	−8.74	8	< 0.001

Source: Field survey, 2026 (SPSS version 26). The negative sign of (t) reflects the order in which the groups were entered.

Field observation checklist

The 15-item checklist (Table 5) shows that 14 of the 15 indicators (93.3%) were recorded as present, and only the presence of seedlings was absent (6.7%). The "present" indicators include extensive tree felling, more than 18 tree stumps, felled logs, kiln sites, active and abandoned production sites, stored charcoal, bare land, ash deposits, and erosion with desert-like conditions. Two of the 14 recorded indicators concern restoration (reforestation activities and awareness signboards) and were present only at low or very low levels, and the canopy indicator refers to the relatively undisturbed area. The count of 14 therefore should not be read as 14 separate degradation indicators; it shows that nearly every sign of charcoal-related disturbance on the checklist was observed and that restoration signs were minimal.

Table 5: Field observation checklist results (15 indicators)

S/N	Observation item	Observation	Status
1	Evidence of tree felling	Observed throughout production areas	Present
2	Presence of tree stumps	More than 18 tree stumps recorded	Present
3	Large number of felled trees/logs	Observed at homes, farms and charcoal sites	Present
4	Charcoal kiln sites	More than 3 kiln sites observed	Present
5	Active charcoal production	Three active production sites recorded	Present
6	Presence of tree canopies	More than 32 trees observed in the undisturbed area	Present
7	Abandoned charcoal sites	Four abandoned kiln sites observed	Present
8	Charcoal bags/storage areas	More than 15 bags observed	Present
9	Reduction in vegetation cover	Bare land and degraded vegetation observed	Present
10	Deforested/bare land	Many bare-land areas recorded	Present
11	Ash deposits	Observed around abandoned kiln sites	Present
12	Evidence of land degradation	Erosion and desert-like conditions recorded	Present
13	Reforestation activities	Very limited	Present (low)
14	Environmental awareness signboards	Only one NYSC CDS signboard observed	Present (very low)
15	Presence of seedlings	No seedlings observed	Absent
	Summary	**Present: 14 (93.3%); Absent: 1 (6.7%); Total: 15 (100%)**	

Source: Field survey, 2026.

The field observations reinforced the tree-density result. Charcoal sites showed extensive cutting, numerous stumps, reduced canopy, bare ground, erosion features, active and abandoned kilns, wood stockpiles and limited seedlings, whereas the relatively undisturbed areas retained denser canopy, minimal bare land, rare erosion and seedlings outside production areas. Ash deposits around abandoned kilns suggest repeated use of the same sites without adequate recovery periods.

Production practices and species pressure

Traditional earth-mound and earth-pit kilns were observed. Their continued use reflects low start-up costs and familiarity, but these methods can be inefficient and wood-intensive

(Chidumayo & Gumbo, 2013). Interviews identified neem (*Azadirachta indica*), shea butter tree (*Vitellaria paradoxa*), tamarind (*Tamarindus indica*) and chew-stick tree (*Salvadora persica*) as frequently used species. The repeated harvesting of useful indigenous trees creates an ecological and social trade-off: species that provide shade, food, medicine, soil protection or cultural value are also treated as readily available fuelwood.

Afforestation and restoration practices, and community perceptions

The evidence points to a gap between recognition of restoration needs and actual restoration capacity (Table 6). Field observations found very low tree-planting activity, no seedlings around production sites, poor natural regeneration and only one environmental awareness signboard. Key informants acknowledged the importance of tree planting but reported that replanting was insufficient compared with the rate of harvesting, and that few residents replace the trees they cut. Barriers identified were inadequate access to seedlings, water shortages, limited environmental education and weak institutional support.

Table 6: Indicators of afforestation practices

Indicator	Observation
Tree-planting activities	Very low
Presence of seedlings	None observed in production areas
Environmental awareness campaigns	Only one NYSC CDS signboard
Natural regeneration	Poor

Source: Field survey and key informant interviews, 2026.

The community's position on restrictions was conditional and not uniformly oppositional (Table 7): 42.7% supported restrictions outright, 54.5% supported them only where sustainable alternatives were available, and 2.7% opposed them. Interviewees proposed employment creation, alternative livelihood programmes, stronger regulation, provision of seedlings, awareness campaigns, affordable clean energy and improved afforestation.

Table 7: Community support for restrictions on charcoal production

Response	Frequency (*f*)	Percentage (%)
Yes (support restrictions)	47	42.7
No (oppose restrictions)	3	2.7
Depends (support only if alternatives are available)	60	54.5
Total	**110**	**100.0**

Source: Questionnaire survey, 2026. Percentages are of N = 110; the listed values sum to 99.9 because of rounding. Means and standard deviations are not reported for this categorical item.

Socio-economic factors reported as motivating charcoal production

Every questionnaire respondent (100.0%) named poverty as a reason for charcoal production, followed by the need for income (95.5%), household energy needs (76.4%), high demand for charcoal (45.5%) and lack of alternative jobs (29.1%); only one respondent (0.9%) named ignorance (Table 8). In a separate item, 99.1% agreed that poverty and unemployment contribute to charcoal production (Table 9). Interviewees likewise described poverty, limited employment opportunities (particularly for youths), high and sustained demand for charcoal as an affordable cooking fuel, and the high cost of cooking gas as the

factors sustaining the activity; farmers described charcoal as supplementary income when agricultural output is low.

Table 8: Reasons reported for engaging in charcoal production (multiple responses)

Reported reason	Frequency (n = 110)	Percentage (%)
Poverty	110	100.0
Source of income	105	95.5
Household energy needs	84	76.4
High demand for charcoal	50	45.5
Lack of alternative jobs	32	29.1
Ignorance	1	0.9

Source: Questionnaire survey, 2026. Respondents could select more than one reason, so percentages (of N = 110) do not sum to 100%.

The activity therefore appears to function mainly as an economic coping strategy rather than a preferred occupation. This reading is supported by the finding that 62.7% of respondents would stop producing charcoal if viable alternative livelihoods became available; 25.5% were uncertain and 11.8% would continue (Table 9).

Table 9: Perception of poverty and unemployment as drivers, and willingness to stop charcoal production if alternative livelihoods become available

Response	Poverty and unemployment contribute to charcoal production, f (%)	Would stop producing charcoal if alternatives were available, f (%)
Yes	109 (99.1%)	69 (62.7%)
No	1 (0.9%)	13 (11.8%)
Not sure	0 (0.0%)	28 (25.5%)
Total	**110 (100.0%)**	**110 (100.0%)**

Source: Questionnaire survey, 2026.

Discussion

The discussion is organised around the three objectives. For each, the magnitude of the evidence and its limits are considered before implications are drawn.

Vegetation condition

The comparison provides a clear local signal: heavily exploited charcoal sites had about 70% fewer trees than relatively undisturbed sites (about 85 against 280 trees ha^{-1}), a difference of roughly 195 trees ha^{-1} that was statistically significant $t(8) = -8.74$, $p < 0.001$). The magnitude is large, but its interpretation is constrained by the design. The ten plots were located purposively, there were only five per category, and the analysis is sensitive to the selection of individual plots; the contrast therefore cannot be taken as a community-wide estimate for Kudai. The design is also observational and cross-sectional, with no pre-disturbance baseline. Farming, grazing, firewood collection, rainfall variability and prior land-use history may also influence tree density, and land degradation generally has several interacting pathways (Prăvălie, 2021). Nevertheless, the consistency between the statistical comparison, visible kiln activity, stump evidence, ash deposits, bare soil and limited regeneration makes charcoal production a highly plausible contributor to the observed difference. This pattern accords with Salifu (2013) in northern Ghana and Adebayo et al. (2019) in Oyo State, who associated charcoal production with forest depletion, soil change

and deforestation. The difference we found is also of a similar order to the 74.2% reduction in tree cover at charcoal sites in Zambia (Sedano et al., 2022), although the two measures and designs differ and should not be compared directly. The frequent use of neem, shea butter, tamarind and chew-stick trees parallels the pressure on *Vitellaria paradoxa* reported by Adebayo et al. (2019), and the continued use of earth-mound and earth-pit kilns is consistent with the wood-intensive, low-efficiency production described by Chidumayo and Gumbo (2013).

Afforestation, restoration and community perceptions

The evidence on this objective is the weakest in quantitative terms. It rests on field indicators (very low planting, no seedlings, poor regeneration, one signboard), ten key informant interviews and one questionnaire item on restrictions, and it is not a representative survey of community perceptions; its conclusions are therefore indicative. Within that limit, the findings suggest that awareness of the value of trees does not by itself produce restoration, because seedlings, water, institutional support and environmental education are lacking. This agrees with Chomini et al. (2022), who linked weak traditional governance and live-tree harvesting to poor replenishment in Bauchi State, and with Pelletier et al. (2021), who showed that land tenure and labour relations shape the environmental footprint of charcoal. The conditional pattern of support for restrictions (54.5% conditional, 42.7% outright, 2.7% opposed) is consistent with households that depend on the activity and see restrictions as acceptable only if alternatives exist.

Reported socio-economic motivations

Poverty, the need for income and household energy needs were the factors most often reported, in line with Olasimbo and Johnson (2018) in Oyo State, Chomini et al. (2022) in Bauchi State and the wider value-chain literature (Zulu & Richardson, 2013). Two cautions apply. First, these are factors reported or perceived by residents; the study did not test which are statistically associated with actual participation, and only seven of 110 respondents (6.4%) were producers, so the results describe community perceptions more than producers' own decisions. Second, self-reported motivations and stated intentions may differ from behaviour: that 62.7% would stop producing charcoal if alternatives were available is an expressed intention, and 25.5% were uncertain. Poverty and income needs were reported far more often than lack of alternative jobs (29.1%), although 99.1% agreed in a separate item that poverty and unemployment contribute to the activity. Two conclusions follow. First, environmental awareness does not automatically produce conservation behaviour when households face poverty and energy insecurity. Second, a blanket restriction without alternative income and energy provision could shift hardship onto producers without resolving demand for charcoal.

Implications

Within these limits, the findings point towards an integrated transition and not towards restriction alone. Regulation should protect vulnerable and ecologically important species but should be combined with community restoration, affordable clean cooking options, vocational training, agricultural value addition and employment schemes. Because progress towards clean cooking is slow in sub-Saharan Africa (Stoner et al., 2021) and misconceptions

about charcoal can distort policy (Mwampamba et al., 2013), such measures should be paced and evidence-based. Restoration should not be reduced to distributing seedlings: survival depends on water, tenure, local stewardship, protection from grazing and monitoring over time. Producers should also take part in designing rules, because locally legitimate arrangements are more likely to be followed than purely punitive controls (Pelletier et al., 2021).

Conclusion

In the plots sampled, heavily exploited charcoal-production areas in Kudai had markedly lower tree density than nearby relatively undisturbed areas (about 85 against 280 trees ha^{-1}; $p < 0.001$), and field observations recorded visible land-surface disturbance and almost no regeneration. These findings are consistent with charcoal production being a major contributor to local vegetation degradation, but because the study is observational, based on ten purposively located plots and confined to one community, they indicate a strong association and not a complete causal estimate, and they do not establish the full environmental effects of charcoal production across Kudai, Dutse LGA or Jigawa State. Charcoal production remains economically important because households use it for income and energy; residents most often reported poverty, income needs and household energy needs as reasons for it, and support for environmental controls was substantial but conditional on credible alternatives. The evidence supports a transition from unmanaged extraction towards a community-based system that protects vegetation while addressing the material realities that sustain charcoal production.

Recommendations

1. Establish community-managed restoration zones with locally appropriate indigenous species, seedling nurseries and seasonal survival monitoring.
2. Provide affordable clean-cooking options and energy-efficiency education, prioritising households most dependent on charcoal.
3. Develop alternative livelihood packages: vocational skills, small-enterprise grants, agricultural processing, livestock support and youth employment.
4. Regulate harvesting through permits, protection of priority species, kiln-site controls and transparent monitoring involving community leaders and the Jigawa State Environmental Protection Agency (JISEPA).
5. Where charcoal production continues, promote improved kilns, sustainable woodlots and documented harvesting plans rather than unrestricted cutting.
6. Repeat vegetation surveys annually with randomly or systematically located plots, and add canopy cover, basal area, soil, biomass, carbon and remote-sensing land-cover measurements to create a stronger long-term baseline.

Limitations of the study

The study is limited by (i) its single-community scope; (ii) the small number of vegetation plots (five per category), which were purposively located, so that the comparison is sensitive to individual plots and cannot give a community-wide estimate; (iii) the use of tree density, not a direct measure of canopy or ground cover, as the principal vegetation indicator; (iv) its cross-sectional design, which lacks pre-disturbance baseline data and cannot separate the effects of charcoal production from those of farming, grazing, firewood collection, rainfall variability or earlier land use; (v) reliance on self-reported socio-economic data, with only 7 of 110 questionnaire respondents being charcoal producers, so that the questionnaire results describe perceived motivations and are not tests of association with actual participation; (vi) perception evidence on afforestation drawn from ten key informants and field indicators; and (vii) the absence of laboratory soil, air or water analyses. The findings are therefore most directly applicable to Kudai and should not be generalised to other communities.

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