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Spatial Assessment of Wood Fuel Supply, Distribution and Household Consumption in Zaria Local Government Area, Kaduna State, Nigeria

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ABSTRACT

Wood fuel remains a major household energy source where cleaner substitutes are costly, hard to obtain or unreliable. This study examined the supply, spatial distribution and household consumption of wood fuel in Zaria Local Government Area (LGA), Kaduna State, Nigeria, together with changes in vegetation greenness between 1987 and 2026. Data were obtained from a structured household questionnaire (400 distributed, 384 valid; collected in 2026), field observation and trader interviews, while NDVI change was derived from Landsat imagery (1987, 2007 and 2026) in Google Earth Engine. Commercial vendors were the principal source of wood fuel, with vendor dependence reaching 89.5% in Kwarbai B and 83.3% in Kaura. Twenty depots were identified (3 major and 15 minor wood fuel depots, and 2 charcoal depots), and about 65% of respondents reported that distribution intensified in the dry season. Wood logs (55.75%) and charcoal (38.35%) were the leading forms of wood fuel, cooking was the main use (72.9%), and convenience (28.6%), availability (25.0%) and cost effectiveness (22.9%) were the most frequently reported reasons for use. Dry-season NDVI composites for the three dates were compared pixel by pixel. NDVI depletion (a decrease of more than 0.05) covered 28.03 km² (9.2% of the 303 km² LGA) in 1987–2007 and 10.00 km² (3.3%) in 2007–2026, and 10.21 km² (3.4%) over the whole 39 years, mostly of moderate magnitude. NDVI increased over 15.59 km² (5.1%) and 92.33 km² (30.4%) in the two intervals, an increase that may partly reflect the change from ETM+ to OLI sensors. Vegetation depletion was therefore localised and not continuous. Wood fuel is one of several possible pressures on vegetation alongside agricultural expansion and urban growth, and the study did not test a causal link. Affordable and dependable alternative energy, regulation of tree harvesting and protection of the remaining vegetation are recommended.

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INTRODUCTION

Wood fuel remains an important traditional household-energy resource across developing regions, particularly where cleaner substitutes are not yet affordable, dependable or readily accessible. Nearly 2 billion people worldwide still lack access to clean cooking, about half of them in sub-Saharan Africa (IEA, 2026), and traditional bioenergy has been estimated to account for about 9% of global primary energy and 55% of total wood harvest (Masera et al., 2015). In Nigeria, recent evidence shows that traditional fuels still account for a substantial share of household energy use and that socioeconomic conditions, household characteristics and regional differences shape movement towards modern energy sources (Abubakar et al., 2024; Aminu et al., 2024). Across Africa, access to clean cooking is strongly associated with economic conditions,

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rurality, resource depletion and the availability of energy infrastructure (Onyeneke et al., 2023).

The scale of the challenge is illustrated by national estimates of 23,745,458 tonnes of firewood and 4,828,689 tonnes of charcoal consumed in Nigeria in 2021 (Łaska and Ige, 2023). Wood fuel reaches households through a supply chain that is wider than a simple forest-to-consumer movement. The chain links source areas, itinerant suppliers, large depots, smaller neighbourhood sales points and end users. Mapping this chain matters for environmental management because places with concentrated demand also tend to become centres of harvesting, storage and transport activity. Household energy choices are shaped by income, fuel prices, infrastructure and social preferences, and many households combine several fuels (fuel stacking) instead of moving in a straight line to cleaner ones (Guta et al., 2022; Batchelor et al., 2022).

A substantial body of Nigerian research has examined the drivers of household fuel choice. Affordability, accessibility, household socioeconomic conditions and the availability of alternatives are repeatedly identified as important influences (Baraya et al., 2023; Aminu et al., 2024; Oyeniran et al., 2025). Studies in Oyo State reported that 76% of households depend on fuelwood for cooking and that annual wood consumption exceeds the quantity sustainably extracted from forests (Ogunkunle and Oladele, 2004), and a household survey in Katsina State found a high level of fuelwood dependence that was related to education, employment status, age and household size (Ogujiuba and Muazu, 2022). In the semi-arid north, Baraya et al. (2023) documented the socioeconomic determinants of household energy consumption in Kebbi State. In Zaria and its surrounding region, Dabo et al. (2016) reported that most surveyed households used fuelwood as their major energy source, chiefly because of its cheapness, affordability and availability.

The policy literature increasingly argues for integrated approaches that combine better access to clean cooking technologies with environmental and forest management, rather than relying on fuel substitution alone (WHO, 2023; IEA, 2025; FAO, 2024). Expanding the storage, transport and distribution systems for modern cooking fuels is highlighted as a particular need in Africa (IEA, 2025). Advances in earth observation have made it possible to quantify vegetation change linked to such pressures. Global analysis of 30 m Landsat data mapped 2.3 million km² of forest loss and 0.8 million km² of gain between 2000 and 2012, with the tropics the only climate domain showing a rising trend in loss (Hansen et al., 2013). Platforms such as Google Earth Engine now allow decades of Landsat imagery to be processed efficiently for land-cover change detection (Gorelick et al., 2017).

Despite this literature, studies usually treat household demand, supply-chain logistics or land-cover change in isolation. Few combine fine-scale mapping of the wood fuel supply chain with household consumption behaviour and multi-decadal vegetation change in one framework at the LGA level, which limits the design of geographically targeted interventions. Depot categories, supply flows and the seasonality of distribution in Zaria LGA were described earlier by Samira et al. (2021) from the same 2026 field survey; the present study summarises those results as context, and its novelty lies in integrating them with household consumption and long-term land-cover change. The objectives were to (i) summarise the depot and supply-flow structure of the supply chain, (ii) characterise household fuel forms, uses and reported reasons for use, and (iii) quantify vegetation change over 39 years from Landsat imagery. The aim was to assess the supply, distribution and household consumption of wood fuel in Zaria LGA and to evaluate spatial and temporal changes in vegetation cover from 1987 to 2026, thereby providing a reference point for energy policy and natural-resource management in northern Nigeria.

MATERIALS AND METHODS

A mixed-method design was adopted, combining household questionnaires, vendor interviews, field observation and GIS and remote-sensing analysis. This was necessary because the study required social evidence on energy use

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as well as spatial evidence on depot locations, supply flows and vegetation cover.

Study Area

Zaria LGA lies in Kaduna State, northern Nigeria (Figure 1) and has thirteen wards: Anguwan Fatika, Anguwan Juma, Kaura, Kwarbai A, Kwarbai B, Limancin Kona, Dambo, Dutsen Abba, Gyellesu, Kufena, Tudun Wada, Tukur-Tukur and Wuciciri. The boundary used for the spatial analysis covers 303.4 km². The landscape combines built-up settlements, cultivated land and remnant patches of vegetation, which makes it suitable for examining the relationship between household energy demand, commercial wood fuel circulation and vegetation change.

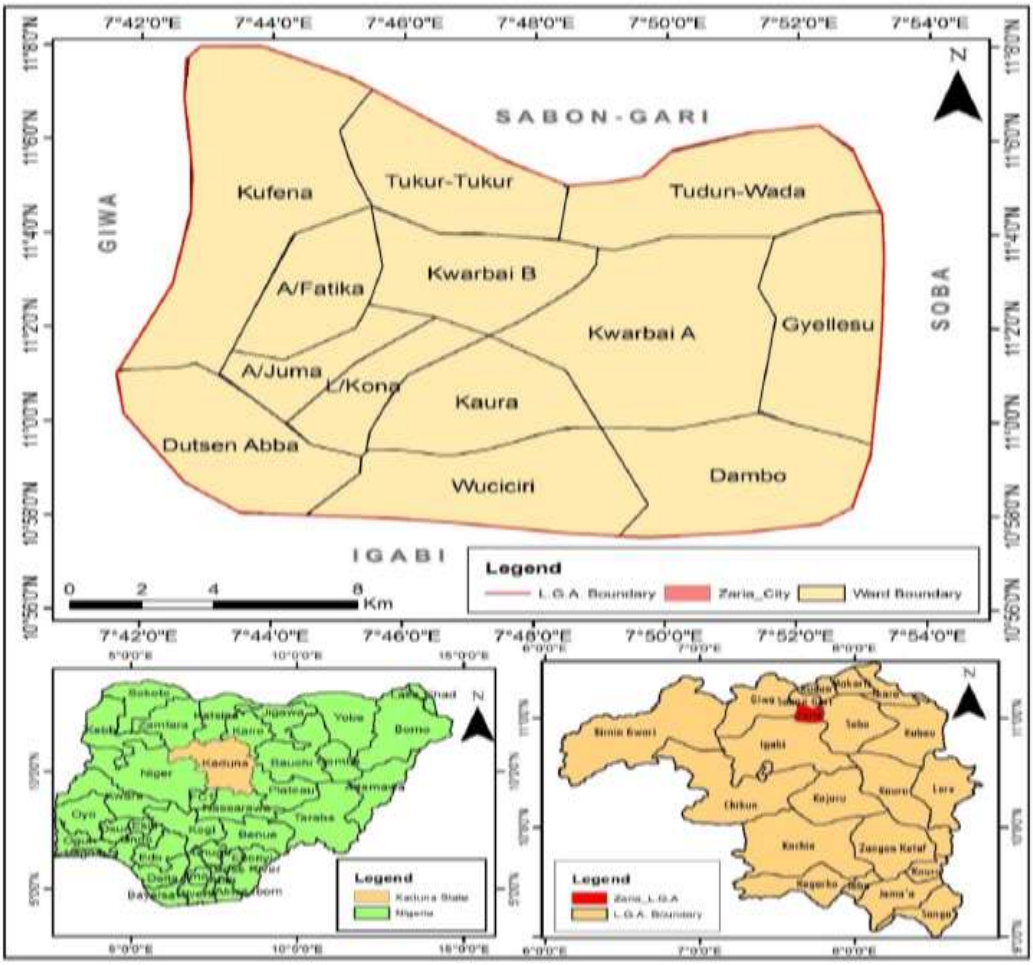


Figure 1. Location and ward configuration of Zaria LGA. Source: Modified from the administrative map of Kaduna State (2026).

Sampling and Data Collection

The household sample size was determined with Yamane's (1967) formula, $n = N / (1 + Ne^2)$, where N is the population of the study area and e is the sampling error. The population of Zaria LGA was projected to 2026 from the 2006 census count (NPC, 2009) at a 3% annual growth rate using $P = P_0(1 + r)^n$, which gave N = 737,129. At a 95% confidence level (e = 0.05), n = 737,129/

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(1 + 737,129 × 0.05²) ≈ 400. Four hundred questionnaires were therefore distributed and allocated to the thirteen wards in proportion to their projected population (Table 1). Of these, 384 (96%) were returned fully completed and were analysed. Respondents were selected by systematic random sampling, taking the first house and then every fifth house along each street in a ward, and one adult respondent per household answered.

The structured questionnaire covered respondent characteristics, sources of wood fuel, fuels used, forms and purposes of use, preferred tree species and reasons for using wood fuel. It was validated through expert review and a pilot test with respondents outside the sample. Interviews were also held with wood fuel vendors and selected residents, and wood fuel and charcoal depots were identified in the field and their coordinates recorded with a handheld GPS receiver. Fieldwork was carried out in 2026.

Table 1. Allocation of questionnaires across the wards of Zaria LGA.

Ward	Projected population	Questionnaires allocated	Valid responses
Anguwan Fatika	50,287	35	34
Anguwan Juma	42,391	28	27
Kaura	42,391	32	30
Kwarbai A	41,358	34	33
Kwarbai B	97,543	27	25
Limancin Kona	100,837	31	30
Dambo	36,917	29	28
Dutsen Abba	74,151	33	32
Gyellesu	50,103	30	29
Kufena	37,597	26	25
Tudun Wada	36,577	34	32
Tukur-Tukur	84,586	32	30
Wuciciri	42,391	29	29
Total	**737,129**	**400**	**384**

Source: Field survey, 2026

GIS and Remote-Sensing Procedures

Vegetation change was assessed from Landsat Collection 2 Level 2 surface-reflectance imagery processed in Google Earth Engine (Gorelick et al., 2017). Three epochs were analysed: 1987, 2007 and 2026. 1987 is the earliest year for which usable dry-season Landsat coverage of Zaria LGA was available and serves as the baseline; 2026 is the most recent complete dry season (November 2025 to February 2026); and 2007 lies approximately midway, giving intervals of about 20 and 19 years. differed markedly from the other dates in its NDVI distribution and spatial pattern and could not be compared with them. Each epoch was represented by a dry-season median composite from Landsat 5 Thematic Mapper (TM, 1987), Landsat 7 Enhanced Thematic Mapper Plus (ETM+, 2007) and Landsat 8/9 Operational Land Imager (OLI, 2026) at 30 m resolution (Table 2).

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Table 2. Landsat imagery used to derive the NDVI composites.

Year	Sensor	Path/Row	Resolution
1987	Landsat 5 TM	189/052	30 m
2007	Landsat 7 ETM+ (gap-filled)	189/052	30 m
2026	Landsat 8 OLI	189/052	30 m

Source: USGS Landsat Collection

For each date, cloud, cloud-shadow and snow pixels were removed with the QA_PIXEL band, the digital numbers were scaled to surface reflectance, and the Normalized Difference Vegetation Index, NDVI = (NIR − Red) / (NIR + Red) (Tucker, 1979), was calculated. A per-pixel median composite of the valid scenes was built for each date and clipped to the LGA boundary. Composites were limited to the dry season (February) to reduce phenological differences between dates, and pixels without valid data were masked. Landsat 7 ETM+ scenes acquired after May 2003 contain scan-line gaps, which were filled using Qgis to fill the.

The composites were exported at 30 m resolution and compared pixel by pixel. For each pair of dates, ΔNDVI = NDVI of the later date − NDVI of the earlier date. Depletion was defined as ΔNDVI < −0.05, an increase as ΔNDVI > +0.05, and all other pixels as stable. The ±0.05 threshold was chosen to exceed typical composite noise and sensitivity to thresholds of 0.03 and 0.10 was tested. Depletion was further divided into moderate (−0.10 to −0.05), strong (−0.20 to −0.10) and severe (below −0.20) classes. Class areas were calculated from pixel counts using the latitude-corrected area of each 30 m cell and expressed in km² and as a percentage of the 303.4 km² LGA boundary, and annual depletion was calculated as depleted area divided by the number of years.

To check that the composites are comparable, the mean, median, standard deviation and 5th–95th percentile range of NDVI were calculated for each date, together with the pixel-by-pixel correlation between dates, and the repeatability of a composite was tested by differencing two 2026 composites built from different scene sets. Wood fuel and charcoal depots were georeferenced and incorporated into the spatial maps. Supply and distribution flow lines linking major and minor depots with receiving settlements were mapped in ArcGIS 10.8.2, based on information obtained from trader interviews and field observations. Maps are displayed in geographic coordinates (WGS 84).

Data Analysis

Questionnaire data were analysed descriptively using frequencies and percentages in SPSS version 23. The denominator for each percentage is stated with the relevant table or figure. Because the survey was designed to describe patterns of supply and use, and the reasons for using wood fuel are self-reported, no inferential test of determinants was applied, and the findings are reported as reasons given by respondents. Spatial outputs were interpreted together with field observations and interview accounts.

RESULTS

Sources of Wood Fuel

Respondents obtained wood fuel from forests, farmlands and commercial sellers, and vendors were the leading source. Reliance on vendors was highest in Kwarbai B (89.5%) and Kaura (83.3%). Direct forest sourcing was comparatively prominent in Dambo, Gyellesu and Dutsen Abba, whereas Anguwan Fatika recorded the strongest representation of farmland sourcing.

Structure of Wood Fuel Depots

The depot, supply-flow and seasonality results in Sections 3.2 to 3.4 were first reported by Samira et al. (2021). They are summarised here to provide the context for the household consumption and vegetation results that follow. The field survey identified 18 wood fuel depots and 2 charcoal depots, giving 20 in all (Figure 2).

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Major depots (Tudun Wada, Old Jos Road and Dutsen Abba) functioned as large receiving, splitting and redistribution centres that supplied smaller sellers, while minor depots were smaller sales points serving consumers more directly. The two charcoal depots were located in the Wusasa area. The depots were concentrated around residential and built-up areas, which increased the physical accessibility of wood fuel.

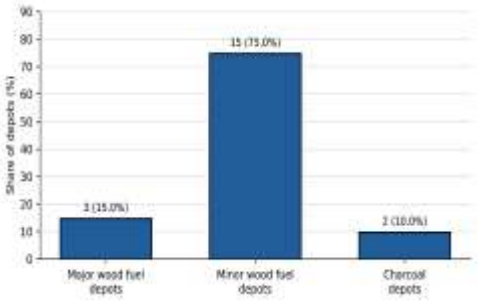


Figure 2. Wood fuel and charcoal depot categories in Zaria LGA (N = 20 depots; labels show number and percentage). Source: Field survey, 2026.

Spatial Distribution and Supply Flow

The flow analysis (Figure 3) shows substantial outward movement from the Tudun Wada major depot towards settlements around Wuciciri, Tukur-Tukur and Dakace. Strong movement was also recorded from the Old Jos Road depot towards Dakace and Gyellesu, and from the Dutsen Abba depot towards Tudun Wada. Charcoal from the two Wusasa depots was distributed mainly to settlements around Tukur-Tukur, Gyellesu and Dakace. These links indicate that wood fuel trading is organised around identifiable redistribution nodes rather than being a set of isolated transactions.

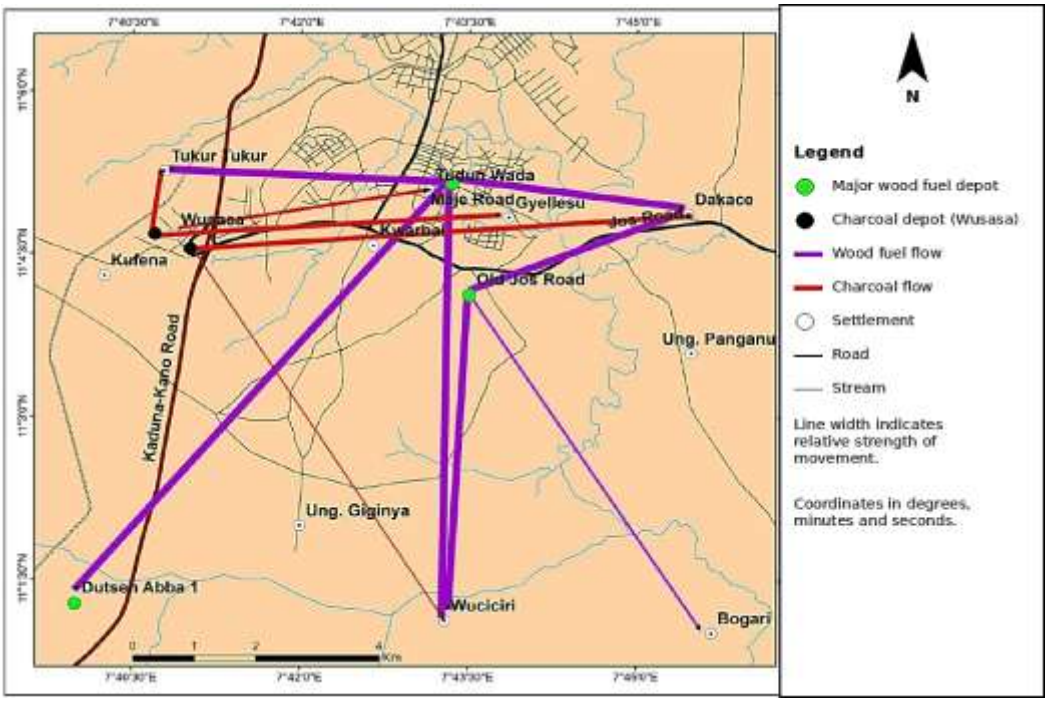


Figure 3. Spatial flow of wood fuel and charcoal from major depots in Zaria LGA. Source: Field survey, 2026.

Seasonality and Means of Transport

About 65% of respondents said that wood fuel distribution was more pronounced in the dry season. Supplies reached consumers at various times of the day, with pickup trucks the principal means of transport (55.5%), followed by

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wheelbarrows (30.5%), other means (10.4%) and animal-drawn pushcarts (3.6%). The largest shares of respondents received supplies at any time of the day (32.8%) or in the morning (31.5%). Mobile suppliers fed stationary sellers, creating a linked wholesale-to-retail chain (Table 3).

Table 3. Selected characteristics of wood fuel distribution in Zaria LGA.

Distribution feature	Main finding
Peak season	Dry season (65% reported higher distribution)
Means of conveyance	Pickup trucks (55.5%); wheelbarrows (30.5%); others (10.4%); animal pushcarts (3.6%)
Time of supply	Any time (32.8%); morning (31.5%); afternoon (21.4%); evening (14.3%)
Vendor types	Mobile and stationary
Main spatial pattern	Major depots to minor depots and settlements
Important destination clusters	Wuciciri, Tukur-Tukur, Dakace, Gyellesu, Tudun Wada

Source: Field survey, 2026.

Principal Household Cooking and Heating Fuels

Fuel wood was the principal household fuel for 48.4% of respondents, followed by cooking gas (26.0%), kerosene (14.6%), electric cooker (9.1%) and solar power (1.8%) (Figure 4).

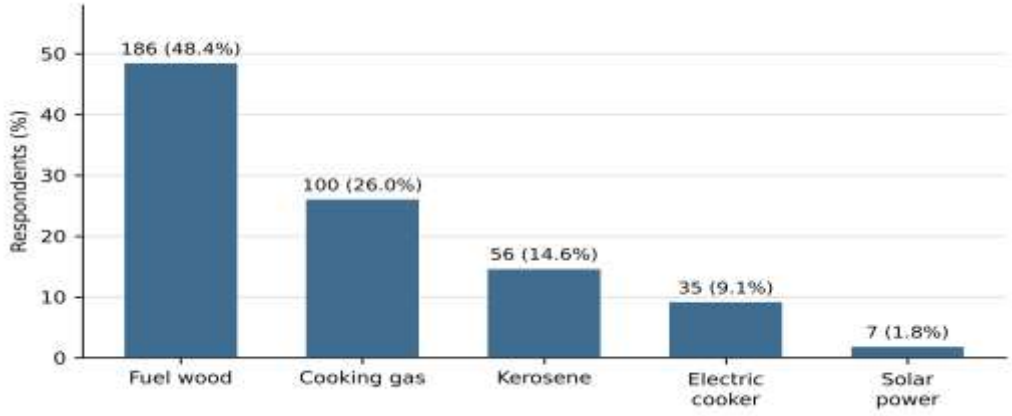


Figure 4. Principal household fuel for cooking and heating (n = 384; labels show frequency and percentage). Source: Field survey, 2026.

Wood Fuel Forms and Household Uses

Wood logs were the most commonly reported form of wood fuel, accounting for 55.75% of the 339 responses recorded, followed by charcoal (38.35%). Other forms accounted for the remaining 5.90% (Table 4). The response base of 339 differs from the 186 respondents who identified wood fuel as their principal household fuel in Figure 4 because the two measures capture different dimensions of household energy consumption. Figure 4 shows the principal fuel, whereas Table 4 considers the forms of wood fuel reported by respondents, including use as a supplementary energy source. This reflects fuel stacking, whereby households combine wood fuel with other energy sources, so households that named gas, kerosene or another fuel as principal could also report using wood logs or charcoal.

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Regarding household uses, cooking was the predominant purpose of wood fuel consumption, accounting for 72.9% of responses, followed by heating bathing water (23.7%) and warming the house (3.4%) (Table 5). The percentages in Table 5 were calculated with the 384 valid questionnaires as the denominator, whereas Table 4 is based on the 339 responses on forms of wood fuel. The two tables are presented separately because they have different response bases.

Table 4. Forms of wood fuel consumed (base = 339 responses).

Form of wood fuel	Frequency	Percent (%)
Wood logs	189	55.75
Charcoal	130	38.35
Sawdust	9	2.65
Dry leaves/bark	6	1.77
Other forms	5	1.47
Total	**339**	**100.0**

Table 5. Stated purposes of wood fuel use (n = 384).

Purpose	Frequency	Percent (%)
Cooking	280	72.9
Heating bathing water	91	23.7
Warming house	13	3.4
Total	**384**	**100.0**

Source: Field survey, 2026.

Preferred Tree Species

Respondents named nine tree species as their preferred fuelwood (Table 6, Figure 5). Marke (*Anogeissus leiocarpa*) was the most preferred (26.30%) due to its slow burning efficiency and low smoke output effect, followed by Doka (*Isoberlinia doka*, 20.57%), Tsamia (*Tamarindus indica*, 13.54%) and Kadanya (*Vitellaria paradoxa*, 13.28%), and these four species together accounted for 73.70% of respondents. Concentrated demand for a few species can place uneven harvesting pressure on them and raise the risk of local depletion.

Table 6. Preferred species of fuelwood (n = 384).

Local name	Species	Frequency	Percent (%)
Marke	*Anogeissus leiocarpa*	101	26.30
Doka	*Isoberlinia doka*	79	20.57
Tsamia	*Tamarindus indica*	52	13.54
Kadanya	*Vitellaria paradoxa*	51	13.28
Kiriya	*Prosopis africana*	30	7.81
Taura	*Detarium microcarpum*	26	6.77
Samji	*Ficus platyphylla*	24	6.25
Dorowa	*Parkia biglobosa*	16	4.17
Kaiwa	*Diospyros mespiliformis*	5	1.30
Total		**384**	**100.0**

Source: Field survey, 2026.

Reported Reasons for Using Wood Fuel

Convenience in obtaining wood fuel was the most frequently reported reason (28.6%), followed by availability (25.0%) and cost effectiveness (22.9%) (Figure 5). Faster cooking (14.1%), the high or unstable price of alternatives (6.3%) and large household size (3.1%) were less often given. The results suggest that household choices reflect practical constraints of access,

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purchasing power and the dependability of competing fuels, and not only stated preference.

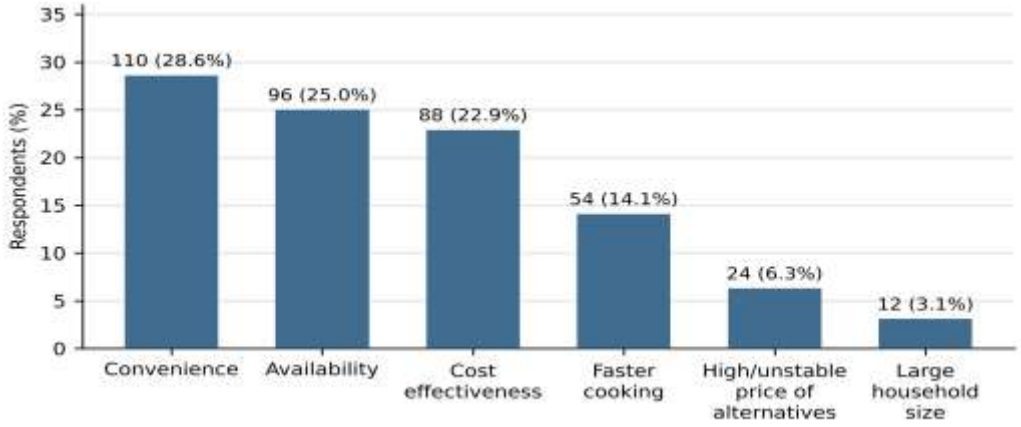


Figure 5. Reported reasons for household wood fuel use. Source: Field survey, 2026.

Vegetation-Cover Dynamics, 1987–2026

Table 6 summarises the three NDVI composites (Figure 6), all of which cover the same 303.4 km². Their NDVI distributions are similar (medians 0.184, 0.173 and 0.204) and their pixel-by-pixel correlations are similar (r = 0.51–0.61), so none is an outlier. The 2007 composite, however, contains faint linear stripes in the north-central part of the LGA that appear to be residual scan-line gaps of Landsat 7 ETM+ (Figure 6b), and these show up as thin linear patches of apparent change in Figure 7a and 7b. The repeatability of the composites was tested by differencing two 2026 composites built from different scene sets: the mean difference was +0.016 (SD 0.017) and 12.0 km² exceeded ±0.05, of which only 1.2 km² was a decrease and 10.8 km² an increase. Composite noise is therefore small relative to the depletion reported below, but not relative to the increases.

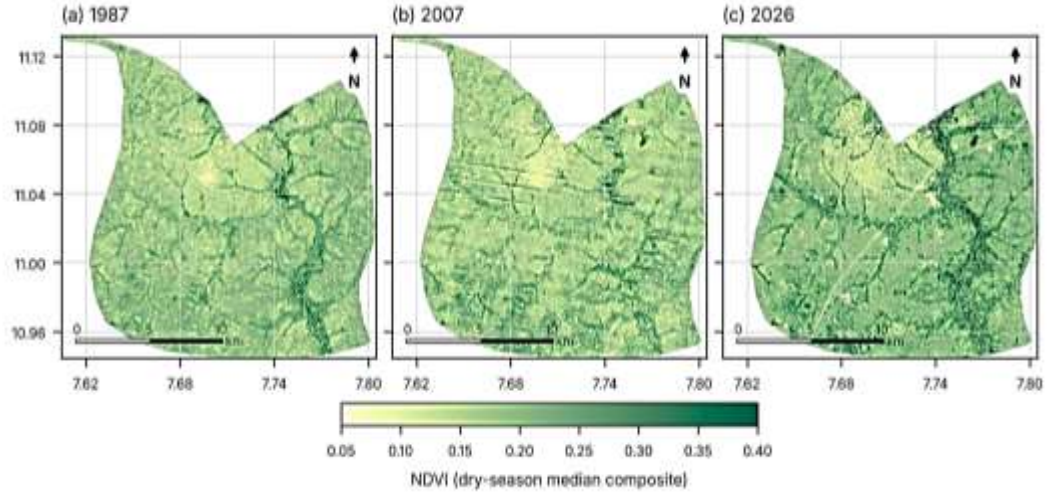


Figure 6. NDVI composites of Zaria LGA for (a) 1987, (b) 2007 and (c) 2026 (dry-season median composites, same colour scale in all panels). Source: Landsat analysis in Google Earth Engine.

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Table 6. Summary of NDVI in the three composites (303.4 km², 30 m pixels).

Year	Sensor	Mean	Median	SD	5th–95th percentile
1987	TM	0.187	0.184	0.041	0.131–0.258
2007	ETM+	0.181	0.173	0.043	0.127–0.260
2026	OLI	0.214	0.204	0.056	0.135–0.319

Source: Landsat analysis in Google Earth Engine, 2026.

Between 1987 and 2007, the interval least affected by sensor differences, NDVI depletion covered 28.03 km² (9.2% of the LGA) and increases covered 15.59 km² (5.1%), a net decrease of 12.45 km² and a mean ΔNDVI of −0.007 (Table 7). Most of the depletion was of moderate magnitude (24.83 km²), with 3.04 km² strong and 0.16 km² severe (Table 8), and the depletion class expanded at about 1.4 km² per year. The depleted areas appear as scattered patches, along the valley and stream corridor in the east and as a compact patch in the north (Figure 7).

Between 2007 and 2026, depletion covered 10.00 km² (3.3%) and increases covered 92.33 km² (30.4%), a net increase of 82.33 km² and a mean ΔNDVI of +0.034 (Table 7). This interval crosses from ETM+ to OLI and the 2026 composite is shifted upward (median 0.204 against 0.173), so part of the increase may reflect sensor or composite differences (Roy et al., 2016) and is not interpreted as vegetation gain. Depletion detected despite this upward bias is, if anything, conservative.

Over the whole 39 years, 10.21 km² (3.4%) was depleted, of which 7.57 km² was moderate, 2.28 km² strong and 0.36 km² severe, while 75.28 km² (24.8%) increased. Only 0.52 km² was depleted in both intervals, and 15.55 km² that was depleted between 1987 and 2007 had increased again by 2026. The depletion therefore does not form a continuous decline. Its magnitude depends on the threshold: depletion covered 69.7, 20.1 and 22.6 km² in the three periods at a threshold of 0.03, and 3.2, 2.5 and 2.6 km² at 0.10. The net changes of the two intervals (+69.89 km²) differ from the direct 1987–2026 net (+65.07 km²) because class thresholds are not additive between periods.

Table 7. Area of NDVI change classes by period

Period	Depletion km² (%)	Stable km² (%)	Increase km² (%)	Net km²	Mean ΔNDVI
1987–2007	28.03 (9.24)	259.79 (85.62)	15.59 (5.14)	−12.45	−0.007
2007–2026	10.00 (3.30)	201.08 (66.27)	92.33 (30.43)	+82.33	+0.034
1987–2026	10.21 (3.37)	217.92 (71.82)	75.28 (24.81)	+65.07	+0.027

Source: Landsat analysis in Google Earth Engine, 2026.

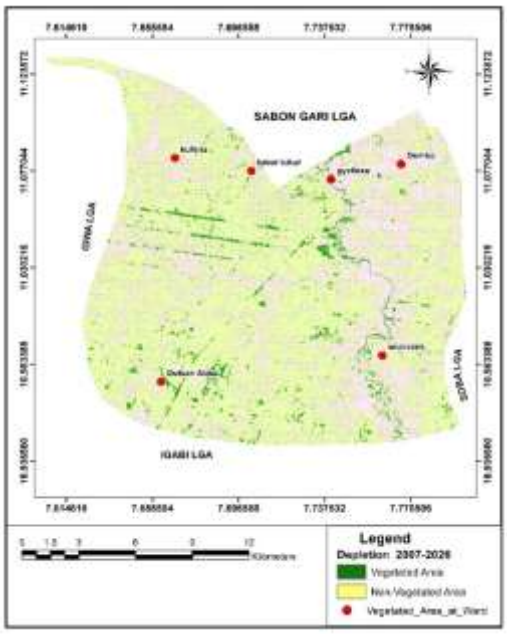
Table 8. Severity of NDVI depletion and annual depletion rate by period (km²).

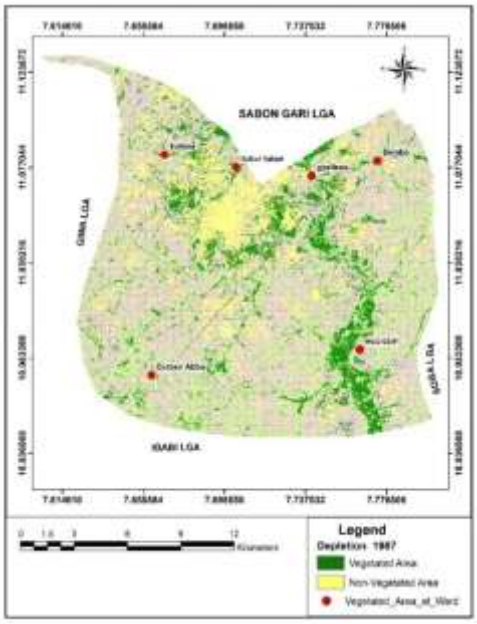
Period	Moderate (−0.10 to −0.05)	Strong (−0.20 to −0.10)	Severe (< −0.20)	Total depletion	Annual rate (km²/yr)
1987–2007	24.83	3.04	0.16	28.03	1.40
2007–2026	7.47	2.25	0.28	10.00	0.53
1987–2026	7.57	2.28	0.36	10.21	0.26

Source: Landsat analysis in Google Earth Engine, 2026.

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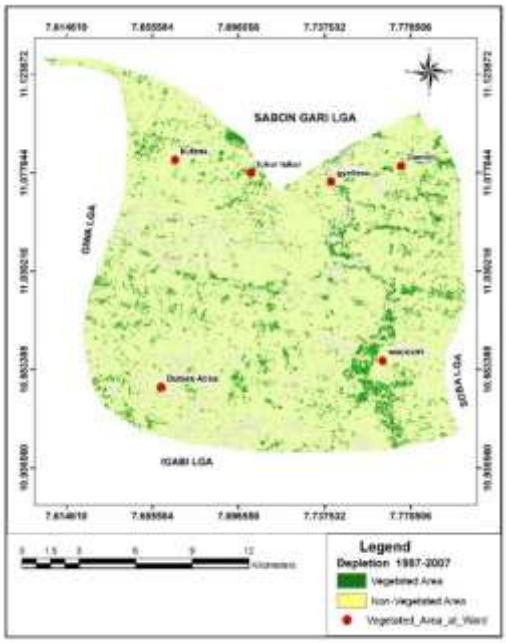


Figure 7. Classes of NDVI) for (a) 1987, (b) 1987–2007 and (c) 2007–2026.

DISCUSSION OF FINDINGS

The results show that wood fuel use in Zaria LGA is closely tied to physical accessibility. Depots located near residential areas reduce the effort needed to obtain fuel, and respondents most often gave convenience, availability and cost effectiveness as their reasons for using it. This is consistent with studies from northern and wider Nigeria showing that affordability, availability, education, household wealth and access to modern energy infrastructure influence household energy choices (Baraya et al., 2023; Abubakar et al., 2024; Aminu et al., 2024), and with the earlier finding for Zaria and its region that cheapness, affordability and availability explain fuelwood use (Dabo et al., 2016).

The picture is also one of fuel stacking (Guta et al., 2022): although wood was the principal fuel for 48.4% of households, over a quarter relied on cooking gas and nearly 15% on kerosene, only 1.8% used solar power, and 339 responses on wood fuel forms exceeded the 186 households naming wood as their principal fuel (Table 4, Figure 4). That the high or unstable price

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of alternatives was given directly by only 6.3% of respondents, while cost effectiveness was given by 22.9%, suggests that wood fuel is perceived as cheap and easy to obtain more than that alternatives are unavailable, a pattern those merits testing with income data in future work.

The mapped supply routes show that wood fuel distribution operates as an organised commercial system. Major depots act as redistribution hubs and minor depots provide neighbourhood-level access, and the high dependence on vendors in wards such as Kwarbai B and Kaura indicates that purchase from vendors is the leading means of obtaining wood fuel. The clean-cooking literature stresses the role of distribution infrastructure and supply chains in expanding access to alternative fuels (IEA, 2025), and the number of people without clean cooking in sub-Saharan Africa was still rising in 2024 despite faster delivery (IEA, 2026). In this setting the same depot network that serves wood fuel suggests where interventions could be targeted, for example by registering and monitoring depots, tracking the origin of supplies and linking clean-fuel distribution to the same nodes. The dry-season peak reported by about 65% of respondents has been linked to the difficulty of gathering dry wood from farmland and forests in the rainy season, when households may turn to charcoal instead (Samira et al., 2021). This has implications for the timing of monitoring and enforcement.

The NDVI composites show that vegetation depletion in Zaria LGA was real but localised, and not continuous. NDVI declined by more than 0.05 over 28.03 km² (9.2% of the LGA) between 1987 and 2007, the interval least affected by sensor differences, and over 10.00 km² (3.3%) between 2007 and 2026. Only 0.52 km² declined in both intervals, and 15.55 km² that had declined by 2007 had increased again by 2026. Over 39 years, 10.21 km² (3.4%) was depleted, mostly at moderate magnitude (Table 8). The larger increases (92.33 km² in 2007–2026) cannot be read as vegetation gain, because that interval crosses from ETM+ to OLI and the 2026 composite is shifted upward, so part of the increase may be a sensor or composite effect (Roy et al., 2016). This localized picture contrasts with the negative NDVI trend reported for the middle Kaduna River catchment between 2000 and 2014, which the authors linked to fuelwood use, cultivation and deforestation (Isa and Danjuma, 2018), and with the growing exposure of land to degradation in semi-arid Katsina State (Ibrahim et al., 2025), and it does not follow the global rise in tropical forest loss (Hansen et al., 2013). It is closer to the loss followed by partial recovery reported for the protected Afaka Forest Reserve near Kaduna, where cover fell by 3.83% between 1986 and 1999 and then recovered by 1.69% to 2018 (Jimoh et al., 2026). With three dates, however, changes within each interval cannot be resolved.

The study does not, however, establish that wood fuel use caused any of the NDVI changes observed. Depot locations, household consumption and NDVI change were mapped and described, but their relationship was not tested statistically, and other drivers, including expansion of cultivated land, urban growth, infrastructure development and rainfall variability, were not quantified. NDVI measures vegetation greenness rather than the loss of particular tree species or woodland, so a decrease may reflect clearing but also crop cycles, drought or land-use conversion. Wood fuel should therefore be regarded as one possible pressure within a wider land-use and energy system (FAO, 2024). Nor do the results show that cleaner energy has relieved pressure on vegetation: modern alternatives such as electric cookers and solar power were still uncommon among respondents in 2026 (Figure 4), but the depletion detected cannot be attributed to any single driver. Future work could relate ward-level NDVI change to depot density, vendor dependence and population growth, and separate natural woodland from cropland.

Several limitations should be noted. Household and vendor data are self-reported and were collected once, in 2026, whereas the vegetation record runs to 2026, so the survey describes energy use at a single point within the period analysed and does not capture later changes. The depot, flow and seasonality results are summarised from an earlier publication of the

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same survey (Samira et al., 2021). NDVI change measures greenness and does not distinguish natural woodland from cropland or planted trees, and Landsat's 30 m resolution limits detection of scattered trees. Only three dates were analysed, so trends within the intervals cannot be resolved, and the 2007 composite retains faint scan-line stripes from Landsat 7 ETM+ that create thin artefacts of apparent change. The 2007–2026 interval crosses from ETM+ to OLI, so its increases are uncertain (Roy et al., 2016), and results depend on the ΔNDVI threshold: depletion in 1987–2007 ranges from 3.2 km² at a threshold of 0.10 to 69.7 km² at 0.03. Depot numbers reflect those identified during fieldwork and may omit small informal sellers.

CONCLUSION

Wood fuel remains central to household energy supply in Zaria LGA because it is accessible, obtainable and perceived to be affordable. It is distributed through a network of 3 major and 15 minor wood fuel depots and 2 charcoal depots served by mobile and stationary traders, and is concentrated near residential areas. Wood logs and charcoal are the main forms, cooking is the main use, and convenience, availability and cost effectiveness are the main reasons given for use. NDVI composites for 1987, 2007 and 2026 showed localised depletion, not a continuous decline: 28.03 km² (9.2% of the LGA) in 1987–2007, 10.00 km² (3.3%) in 2007–2026 and 10.21 km² (3.4%) over the whole 39 years, mostly of moderate magnitude, with increases that may partly reflect sensor differences. Wood fuel use is one of several possible pressures on vegetation, and the findings point to the need for an integrated response that improves the affordability and dependability of household energy alternatives and protects the remaining vegetation.

RECOMMENDATIONS

1. Improve the affordability, availability and reliability of electricity, LPG and other clean cooking technologies. Expanding clean-cooking access in Africa requires investment in infrastructure, fuel distribution, affordability measures and coordinated policy.
2. Expand community education and strengthen enforcement against uncontrolled tree cutting for wood fuel and charcoal production.
3. Protect remaining vegetation, particularly along the valley and stream corridors where depletion was concentrated, through long-term afforestation and sustainable woodland management, supported by institutional capacity and investment.
4. Use GIS-derived information on depot locations and supply flows to guide environmental surveillance and geographically targeted interventions.
5. Conduct further socioeconomic and spatial research on wood fuel dependence, household welfare, distribution networks and the effects of energy transition, including ward-level analysis of the link between wood fuel demand and vegetation change.

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