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SPECIAL ISSUE: CELEBRATING 20 YEARS OF GEOGRAPHY IN KADUNA STATE UNIVERSITY - ADVANCES AND FRONTIERS IN GEOGRAPHY

Assessment of Density and Smallholder Farmers' Perceptions of *Tamarindus indica* L. In Parkland Agroforestry Systems of Gumel Local Government Area, Jigawa State, Nigeria

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ABSTRACT
Parkland agroforestry systems in the Sahel are critical for livelihoods and ecosystem services, yet they face escalating degradation. The specific status of key indigenous species like *Tamarindus indica* L., vital for soil fertility and farmer resilience, remains inadequately documented in many areas, including the Gumel region of Jigawa State, Nigeria. This study assessed the density of *T. Indica* and smallholder farmers' perceptions of its status and ecological roles within these threatened systems. A mixed-methods approach was employed, combining field inventories across four purposively selected wards (Baikarya, Dantanoma, Garin Barka, and Gusau) with semi-structured interviews (n=60) and focus group discussions (n=4). Quantitative data on tree density were analysed using ANOVA, while qualitative data from interviews and FGDs were processed through thematic and sentiment analysis. Results revealed a critically low mean density of *T. Indica* (0.001125/m²) with no significant differences between locations. Farmers unanimously perceived a decline in the species, primarily attributing it to deforestation, agricultural expansion, and low levels of active regeneration, due to socio-economic pressures and knowledge gaps. The study concludes that despite recognizing its value, a disconnect between farmer awareness and conservation action threatens the species' persistence. The study recommends integrated conservation strategies that combine targeted scientific research, farmer education, and policy reforms grounded in local knowledge to ensure the sustainable management and utilization of T. Indica.

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1 Introduction

Agroforestry, the intentional integration of trees with crops and/or livestock, is recognized as a pivotal strategy for enhancing soil fertility, biodiversity, and farm productivity, particularly in regions grappling with environmental degradation and climate change (Mbow et al., 2020; Bayala et al., 2020). In the arid and semi-arid landscapes of West Africa, parkland agroforestry, a system where trees are scattered in cultivated fields, remains a cornerstone of smallholder agriculture, providing essential ecological and economic services (Sida et al., 2021). Indigenous tree species, such as *Tamarindus indica* L., are particularly valued in these systems for their multifunctional roles, including soil nutrient enhancement through leaf litter, provision of food, fodder, and fuelwood, and contribution to microclimate regulation (Githae et al., 2022; Abdulmajid et al., 2025).

Historically, smallholder farmers in Northern Nigeria maintained soil fertility through traditional fallow periods. However, mounting population pressure and the urgent need for food security have drastically reduced the availability of arable land, leading to shortened fallows and continuous cultivation, which undermines these traditional practices (Daura et al., 2022). This intensification places immense strain on the very tree resources that underpin the agroforestry systems. In the Gumel area of Jigawa State, *T. Indica* has been a dominant and cherished component of the parkland system for generations. Despite its importance, anecdotal evidence and preliminary observations suggest a severe decline in its population, yet a systematic assessment of its current status and the underlying drivers from the farmers' perspective is lacking.

This study is grounded in the Sustainable Livelihoods Framework (SLF) and the Socio-Ecological Systems (SES) Theory. The SLF posits that households deploy five types of capital: natural, human, social, financial, and physical, to pursue livelihood outcomes. *T. Indica* represents a critical component of natural capital, and its degradation directly impacts the resilience and sustainability of local livelihoods. Concurrently, the SES Theory provides a lens to analyse the complex, dynamic interactions between human societies and ecological systems. It helps frame how farmers' perceptions, behaviours, and institutional norms, external drivers (e.g., market forces, climate) create feedback loops that either sustain or degrade the *T. Indica*

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resource base.

Recent literature prioritizes a regional trend of declining tree density in West African parklands, driven by agricultural expansion, unsustainable harvesting for fuelwood, and poor regeneration (Bayala et al., 2020; Sida et al., 2021). Understanding farmer perceptions is crucial, as they are the primary managers of these systems; their knowledge and actions ultimately determine the fate of indigenous tree species (Githae et al., 2022). Therefore, this study aims to bridge this knowledge gap by quantitatively assessing the density of *T. Indica* and qualitatively exploring smallholder farmers' perceptions of its status, threats, and ecological roles in the parkland agroforestry systems of Gumel, Jigawa State. The findings are intended to provide an evidence base for crafting locally relevant and theoretically informed strategies for the conservation and sustainable utilization of this vital species.

2 Materials and Methods

2.1 Study Area

Gumel LGA lies between latitudes 12° 20' N and 12° 42' N, and between longitudes 9° 15' E and 9° 35' E. The study area is approximately 148 km away from the state capital, Dutse, and 120 km Northeast of Kano State. It lies about 30 km South of Nigeria's northern border with the Republic of Niger. It shares administrative boundaries with Maigatari Local Government Area in the North, Gagarawa LGA in the South-East, and Sule-Tankarkar LGA in the Southwest (Figure 1).

The study area lies within the Sudano-Sahelian ecological zone of northern Nigeria and is characterized by a hot semi-arid climate (BSh) under the Köppen-Geiger climate classification. Climatic conditions are marked by a short unimodal rainy season, typically occurring between June and September, followed by a prolonged dry season extending from October to May. Long-term meteorological records for northern Jigawa and adjacent Sahelian regions indicate that mean annual rainfall ranges between 450 and 600 mm, exhibiting high inter-annual variability and frequent intra-seasonal dry spells (NiMet, 2020). Mean annual temperatures remain consistently high, averaging 28-30 °C, while maximum daytime temperatures often exceed 40 °C during the pre-rainy season months of March to May (NiMet, 2020). The dominance of potential evapotranspiration over precipitation for most of the year results in a persistent moisture deficit (Beck et al., 2018). These climatic conditions exert strong control over vegetation dynamics, water availability, and agricultural productivity, rendering rain-fed farming systems particularly vulnerable to climate variability and extremes.

Soils in the study area are predominantly light-textured sandy to sandy-loam soils, which are generally low in organic matter and water-holding capacity (FAO, 2015). The vegetation is typical of the Sahel savanna, a transitional formation within the Sudano-Sahelian zone, shaped largely by the prevailing semi-arid climate. Plant cover is therefore open and discontinuous, consisting of scattered, drought-tolerant trees within grass-dominated and cultivated landscapes. Dominant woody species in the study area include *Parkia biglobosa*, *Vitellaria paradoxa*, *Tamarindus indica*, *Adansonia digitata*, *Balanites aegyptiaca*, *Faidherbia albida*, *Acacia nilotica*, *Acacia sieberiana*, *Diospyros mespiliformis*, *Borassus aethiopum*, and several *Ficus* species (Abdulmajid et al., 2025). In addition, introduced species such as *Azadirachta indica* (Neem) and *Mangifera indica* (Mango) are increasingly retained around settlements and farmlands as part of farmer-managed agroforestry parkland systems, owing to their contributions to soil improvement, microclimate regulation, and livelihood diversification (Bayala et al., 2020).

The 2006 Population and Housing Census recorded a population of 106,371 in Gumel LGA. Based on intercensal projections using official growth rates from the National Population Commission and the National Bureau of Statistics, the population is estimated to have increased to approximately 182,900 by 2022 (CityPopulation.de, 2025). Given the LGA's limited land area (≈237.9 km^2), this growth translates into a rise in population density from about 447 to 770 persons km^{-2}, reflecting increasing pressure on land and natural resources.

Livelihoods in Gumel LGA are largely agrarian, with households relying mainly on rain-fed crop production, livestock rearing, and the use of scattered on-farm trees for food, fuel, and other products. This livelihood structure is consistent with evidence from Jigawa State's agro-ecological zones, where agriculture constitutes the dominant source of employment and income (Garba et al., 2021). Population growth and settlement expansion have contributed to rapid land-use and land-cover (LULC) change across northern Nigeria's Sudan-Sahel landscapes, notably through the expansion of croplands and built-up areas at the expense of natural and semi-natural vegetation (Murtala et al., 2025). These changes have contributed to a decline in indigenous tree species, particularly *Tamarindus indica*, as farm expansion, fuelwood harvesting, infrastructure development, and shortened fallow periods reduce tree retention. As a result, demographic pressure and LULC transformation have emerged as major drivers shaping vegetation structure, species composition, and ecosystem services in the study area.

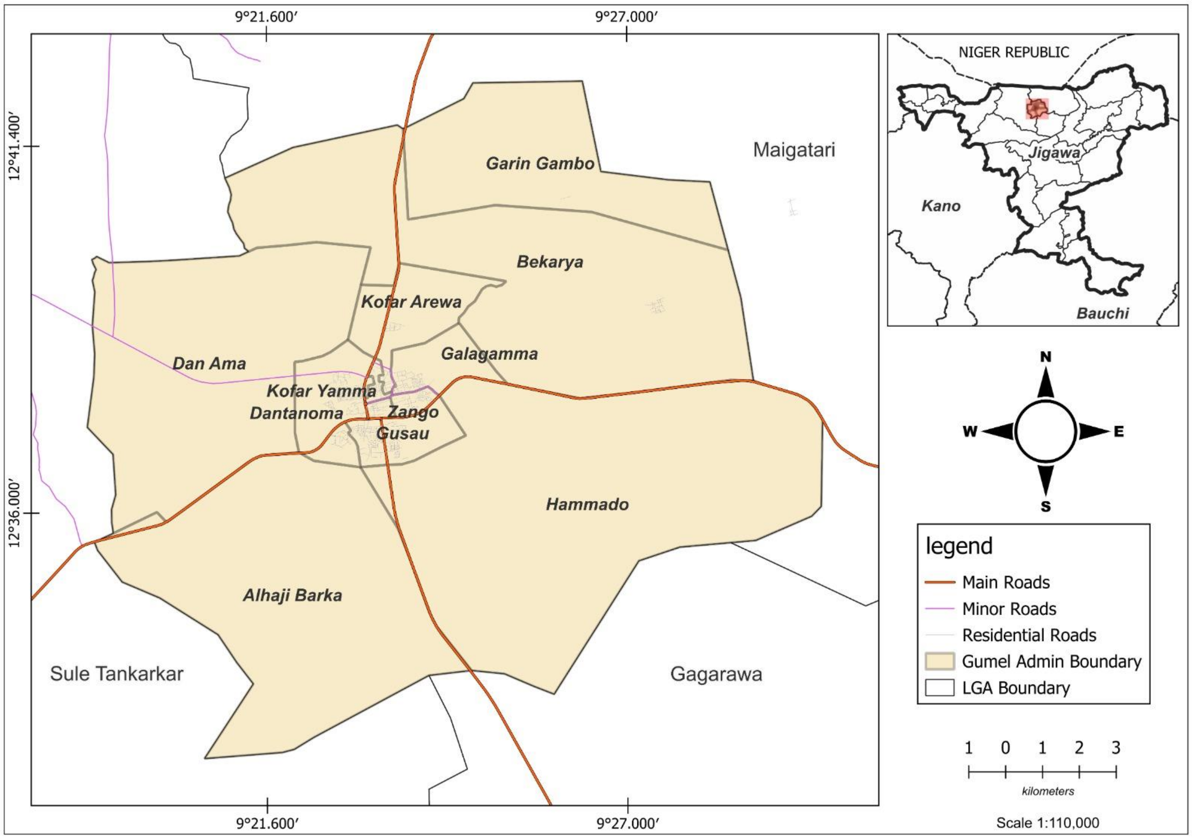

Figure 1. Jigawa State Showing Gumel Local Government Area
Source: Jigawa Geographic Information System (JGIS), Modified by Authors, 2025

2.2 Sampling Procedure

The sampling was conducted in a multi-stage process to ensure focus on active agroforestry parklands. First, Gumel LGA was purposively selected due to the known presence of parkland systems. Second, from the wards within Gumel LGA, four (Baikarya, Dantanoma, Garin Barka, and Gusau) were purposively selected based on two key criteria: (1) their location on the outskirts of Gumel town, where urban expansion has not yet completely displaced farmland, and (2) confirmation from local agricultural extension officers that these wards still maintain active agroforestry practices with the presence of T. *Indica*.

Within each selected ward, the study targeted smallholder farmlands defined as plots smaller than 2ha, in line with regional definitions (Essiet, 1990, as cited in Yakubu, 2020). A specific criterion for plot inclusion was the presence of at least four mature T. *Indica* trees within a 0.4 ha (4000 m²) area, ensuring the study focused on farms where the species is a recognized component of the system. A total of 16 plots (four 0.4 ha plots per ward) were sampled.

2.3 Data Collection

Quantitative data

Field inventories were carried out across all 16 plots. Data collected for every T. *Indica* tree included Diameter at Breast Height (DBH) using a Vernier caliper, tree height using a Haga altimeter, and geographic coordinates using a Garmin GPS device for mapping density distribution.

Qualitative data

Semi-structured interviews (n=60) were administered to farmers, with 15 respondents randomly selected from the farmer list in each of the four wards. This number was determined to achieve data saturation for the key perceptual themes. Additionally, four Focus Group Discussions (FGDs), one per ward, were conducted. While a minimum of 6-8 participants per FGD is often used, the four FGDs with 8-10 participants each were deemed sufficient to capture ward-level consensus and variation, providing rich, contextual data to triangulate the individual interview responses. The interview and FGD guides explored farmers' perceptions of T. *Indica* density trends, causes of decline, ecological benefits, and regeneration practices.

Ethical Consideration

Before commencement, informed consent was obtained verbally from all participants and formally recorded. The study adhered to the ethical guidelines of the Jigawa State Ministry of Agriculture. No endangered species or protected areas were involved.

2.4 Data Analysis

Quantitative data

Tree density (number of trees per m²) was calculated for each plot and ward. A one-way Analysis of Variance (ANOVA) was used to test for significant differences in mean density across the four wards. The analysis satisfied the key assumptions of ANOVA: independence of observations (plots were spatially separate), normality of residuals (tested via the Shapiro-Wilk test), and homogeneity of variances (assessed using Levene's test) (Field, 2024).

Qualitative data

All FGDs and open-ended interview responses were audio-recorded, transcribed verbatim, and translated from Hausa to English. The transcripts underwent a systematic qualitative content analysis (Schreier, 2012). This involved a first cycle of open coding to identify emergent concepts, followed by a second cycle of axial coding to group these concepts into overarching themes (perceived drivers of decline, awareness of benefits, barriers to regeneration). Sentiment analysis was performed by categorizing farmers' overall outlook on the future of T. *Indica* into Negative/Concerned, Neutral, or Positive based on the dominant tone of their responses.

3 Results and Discussion

3.1 Density of *Tamarindus indica*

The field inventory revealed a consistently low density of T. *Indica* across all studied wards, with a mean density of 0.001125 trees/m² (equivalent to approximately 4.5 trees per 0.4 ha plot). As shown in Table 1, densities ranged narrowly from 0.00100/m² in Dantanoma and Gusau to 0.00125/m² in Baikarya and Garin Barka. The ANOVA results confirmed no statistically significant difference in tree density between the four locations ($p > 0.05$).

Table 1: Density of *Tamarindus indica* in the study area

SN	Study Location	Number of Trees (per 4000 m²)	Density (trees/m²)
1	Baikarya	5	0.00125
2	Dantanoma	4	0.00100
3	Garin Barka	5	0.00125
4	Gusau	4	0.00100
	Mean	**4.5**	**0.001125**

The absence of significant spatial variation suggests that the observed low density of *T. indica* is driven by systemic, landscape-scale pressures rather than site-specific factors. Similar patterns have been reported by Saminu (2021) and Bayala et al. (2020) in other Sudano–Sahelian agroforestry parklands, where economically valuable but slow-regenerating tree species persist at low densities due to the combined effects of climatic and human pressures.

Long-term climate variability in the Sahel, particularly since the severe droughts of the 1970s and 1980s, has played a critical role in shaping current vegetation structure. These droughts were associated with a southward shift of rainfall isohyets, a reduction in growing-season length, and increased aridity across northern Nigeria, leading to heightened stress on mesic and semi-mesic tree species (Nicholson, 2013; IPCC, 2021). Although partial rainfall recovery has been observed since the 1990s, increased rainfall variability and rising temperatures continue to constrain natural regeneration and seedling survival in semi-arid environments.

These climatic stresses are further intensified by human-induced land-use changes, including agricultural expansion, fuelwood harvesting, infrastructure development, and shortened fallow periods associated with population growth. While *T. indica* is valued for food and income, it is often selectively removed during land clearing due to its large canopy and perceived competition with crops. Limited active regeneration and weak protection of seedlings within cultivated fields have also contributed to its declining density (Bayala et al., 2020).

The consistently low density of *T. indica* across the study area reflects the combined effects of long-term climate variability and sustained human pressure, highlighting the vulnerability of traditional agroforestry parkland species in the Sudano-Sahelian zone and the need for targeted conservation, assisted regeneration, and climate-smart land-use practices to sustain economically and ecologically important tree species in the region.

3.2 Farmers' Perceptions and the Socio-Ecological System

The qualitative data provide a human dimension to the quantitative findings, and when viewed through the lens of Socio-Ecological Systems (SES) Theory, reveals a system under stress. Farmers demonstrated a high level of awareness of degradation, unanimously perceiving a decline in T. *Indica* populations. They identified key human-driven drivers: deforestation for agriculture and fuelwood, and over-exploitation of mature trees as the primary causes. This directly reflects the SES concept of human actions (resource extraction, land conversion) negatively impacting the ecological subsystem (tree population).

A key finding is that active regeneration of *T. indica* appears to be largely uncommon in the study area. Farmers reported that most existing *T. indica* trees were inherited rather than planted and expressed a widespread perception that tamarind grows naturally and cannot be deliberately planted. From a social-ecological systems (SES) perspective, this belief reflects a critical feedback loop in which ecological conditions, particularly low seedling survival caused by grazing pressure and land-use disturbance, shape social norms that frame T. *Indica* as non-plantable. These norms, in turn, limit human action by excluding active regeneration practices, such as planting or seedling protection, from locally perceived management options, thereby contributing to continued ecological decline.

This locally held perception contrasts strongly with evidence from other dryland regions, where *T. indica* is routinely propagated through seeds and vegetative methods such as cuttings and grafting. In India, T. *Indica* is actively managed within both agroforestry and commercial production systems, while in parts of the Sahel and East Africa, it forms a key component of parkland agroforestry systems (Fandohan et al., 2010). The belief in non-plantability observed in the study area, therefore, appears to be context-specific, likely driven by poor seedling survival under open grazing conditions, limited technical knowledge, and weak extension services, rather than by biological constraints of the species.

This mismatch helps explain the observed awareness–action gap, although farmers recognize the decline of T. *Indica* populations, their mental models and institutional environment do not support active regeneration as a feasible response. Bridging this gap requires targeted extension and knowledge transfer, such as demonstration plots, seedling protection measures, and practical training that connect local ecological realities with proven propagation practices from comparable dryland systems. Such interventions are essential for disrupting the negative SES feedback loops and enabling sustainable T. *Indica* restoration.

The sentiment analysis, summarized in Table 2, further highlights this systemic challenge. The predominance of negative sentiment (75%) indicates a community awareness of a diminishing resource base and its implications for their livelihoods. The small positive fraction (8.3%) likely represents farmers who are either more optimistic about external intervention or have personally experienced the benefits of retained trees.

Table 2: Sentiment Analysis Summary of Farmers' Perceptions

Sentiment Category	Number of Responses	Percentage (%)
Concerned/Negative	45	75.0
Neutral	10	16.7
Positive	5	8.3

Despite the lack of regeneration, farmers highly valued the ecological services provided by T. *Indica*, particularly its role in soil fertility enhancement through leaf litter, corroborating the findings of Abdulmajid et al. (2025). This creates a paradox: they value a resource they are not actively sustaining. The implications are severe; without intervention, this trend suggests a continued loss of a key natural capital asset, leading to reduced soil fertility, diminished resilience to climate shocks, and a decline in the multiple benefits the species provides, ultimately threatening the long-term viability of the entire agroforestry system.

Study Limitations

This study has several limitations. The purposive selection of wards and the specific criterion of farms with at least four T. *Indica* trees means the findings may not be fully representative of all farmlands in Gumel LGA, particularly those where the species has already been completely extirpated. The sample size for FGDs, while providing valuable insights, was limited to one per ward; a larger number might have captured more nuanced community-level differences. Furthermore, the study design is correlational and snapshot-in-time, limiting definitive causal inferences about the drivers of decline.

4 Conclusion

This study provides a stark diagnosis of the state of *Tamarindus indica* in the parkland agroforestry systems of Gumel, Jigawa State. The convergence of quantitative and qualitative data paints a coherent picture of a species in decline. The uniformly low tree density across all study locations is not merely a statistical finding but an ecological reality with profound implications for smallholder livelihoods. More critically, the research uncovers a deep-seated socio-ecological paradox: farmers possess a clear awareness of the species' decline and value its significant contributions to soil fertility, yet this awareness is trapped in a cycle of inaction, stifled by a prevalent belief that the tree cannot be cultivated and a lack of capacity for active regeneration. This dissonance, analysed through the lens of Socio-Ecological Systems theory, highlights a broken feedback loop where ecological degradation reinforces disempowering social norms, which in turn perpetuate the ecological decline. Therefore, the survival of T. *Indica* in these systems hinges not just on technical solutions but on breaking this cycle by integrating local knowledge with scientific support to reshape perceptions and enable collective action.

Based on the findings, a multi-faceted approach is urgently required to reverse the decline of T. *Indica*. The following recommendations are proposed: First, there is a critical need to bridge the gap between farmer awareness and action through targeted extension services. This should involve collaborative programs between government agencies (e.g., Jigawa State Ministry of Agriculture) and NGOs to educate farmers on simple, effective propagation techniques for T. *Indica*, such as direct seeding and seedling management. Demystifying the cultivation process is essential to counter the belief that the tree cannot be planted. These efforts could be incentivized through schemes that provide inputs or link tree conservation to other agricultural benefits. Second, policy frameworks must be strengthened to support on-farm tree conservation. Engaging traditional and community leaders is crucial to revitalize and enforce local bylaws that protect existing trees, particularly from unsustainable harvesting for fuelwood. Furthermore, national agricultural policies should be more inclusive of agroforestry, providing support for farmers who maintain and regenerate indigenous trees on their farmland, recognizing them as active custodians of natural capital. Future research should build upon this foundational study to deepen our understanding.

Further research

Further research should prioritize quantifying the specific ecosystem services provided by T. *Indica,* such as its precise impact on soil organic carbon, nutrient cycling, and microclimate moderation under different management regimes and farm sizes. This would provide robust, economic arguments for its conservation. Additionally, longitudinal studies are needed to monitor the survival and growth rates of farmer-regenerated T. Indica seedlings, and participatory action research could be employed to co-design and test the most effective and culturally acceptable regeneration models with the communities themselves.

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