AFRIGIST Journal of Land Administration and Environmental Management, 2 (2):1-16, 2022
ISSN: 2756-4096 (Online), 2756-410X (Print) doi: https://doi.org/10.54222/ajlaem/v2i2.1
Accepted: November 03, 2022

Fuelwood Gap Theory: Exploring Fuelwood Source Regions in Northern Nigeria's Drylands

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Abstract
Fuelwood consumption, has for a while been assumed to be the ultimate cause of forest degradation, and that if not checked could lead to forest disappearance. This is owed to the fact that over 90 percent of the population of Sub-Saharan Africa is dependent on the resource as a source of energy. Hence, this paper investigates the conformity of the major fuelwood source regions of Northern Nigeria to the Fuelwood Gap Theory. The objectives are; to examine the vegetation cover of the source regions, and identify the major activities at the regions. The methods employed include triangulation of field surveys, Maximum likelihood supervised classification and Post Classification comparison. On the average 77 trees were cut down for every 3600m^2 of farm land. From the maximum likelihood supervised classification result, six major classes were identified namely: forest, water body, woodland, farmlands, built-up area and bare surface. From the post classification done, Dukku Forest Reserve lost 132.9km^2 of the forest class from 1990 to 2018. For the same period, the forest class in Falgore Game reserve increased by 173.36km^2. Lastly, in Rafin Chiyawa Forest Reserve the forest class decreased by 276km^2 from 1990 to 2018. The major activities at the sites include agriculture, sand mining, fuelwood collection and rearing of animals. This indicated that the Fuelwood Gap Theory does not hold for the three Forest Reserves. It is recommended that The Fuelwood Gap Theory be modified to look at forest degradation from a fuelwood consumption-agricultural activities nexus.

Keywords: Fuelwood, Fuelwood Gap Theory, FGR, DFR, RFR

Théorie de l'écart de bois de feu: exploration des régions sources de bois de feu dans les zones arides du nord du Nigéria

Resume
La consommation de bois de feu a longtemps été considérée comme la cause ultime de la dégradation des forêts qui, si elle n'est pas maîtrisée, pourrait entraîner la disparition des forêts. Cela est dû au fait que plus de 90% de la population de l'Afrique subsaharienne dépend de la ressource comme source d'énergie. Par conséquent, cet article étudie la conformité des principales régions sources de bois de feu du nord du Nigéria à la théorie de l'écart de bois de feu. Les objectifs sont les suivants : examiner le couvert végétal des régions sources et identifier les principales activités dans les régions. Les méthodes employées comprennent la triangulation des enquêtes sur le terrain, la classification supervisée du maximum de vraisemblance et la comparaison des postes de classification. En moyenne, 77 arbres ont été abattus pour 3600m2 de terres agricoles. À partir du résultat de la classification supervisée selon la probabilité maximale, six grandes classes ont été identifiées, à savoir : forêt, plan d'eau, boisé, terres agricoles, zone bâtie et surface nue. D'après la post-classification effectuée, la réserve forestière de Dukku a perdu 132,9 km2 de *la classe forestière de 1990 à 2018. Pour la même période, la classe forestière dans la réserve de Falgore a augmenté de 173,36 km^2. Enfin, dans la réserve forestière de Rafin Chiyawa, la classe forestière a diminué de 276 km2 entre 1990 et 2018. Les principales activités sur les sites comprennent l'agriculture, l'extraction de sable, la collecte de bois de feu et l'élevage d'animaux. Cela indique que la théorie de l'écart de bois de feu ne tient pas pour les trois réserves forestières. Il est recommandé de modifier la théorie de l'écart de bois de feu pour examiner la dégradation des forêts à partir d'un lien entre la consommation de bois de feu et les activités agricoles.*

Mots-clés : bois de feu, théorie de l'écart de bois de feu, FGR, DFR, RF

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1. INTRODUCTION

Fuelwood is the primary energy source in Sub-Saharan Africa (SSA), especially for cooking (FAO, 2010; Iiyama, Neufeldt, Dobie, Njenga, Ndegwa, & Jamnadass,2014; International Energy Agency (IEA), 2017; FAO, 2017; Scheid, Hafner, Hoffmann, Kächele, Sieber, & Rybak,2018), it is only becoming that there will be the common perception that fuelwood collection is the major cause of deforestation. However, this view was believed to be further influenced by the Fuelwood Gap theory. The fuelwood gap theory was based on the projection that there was a direct linkage between fuelwood consumption and population growth. The main premise of this theory was formulated on the notion that increasing deforestation problems were interpreted as a problem of a growing gap between population- driven demand and diminishing resources, usually radiating out from centres of habitation in increasingly wider circles, (Anderson & Fishwick, 1984; Timberlake, 1985; Maconachie, Tanko & Zakariyya, 2009).

Growing population in both rural and urban areas means more mouths to feed, more energy needed for day to day living. Thereby, more forest land will be cleared for agriculture that provides ready and available fuelwood. Over time, more fuelwood will be required and hence more trees to meet the demand, setting in soil erosion from wind and water action, compaction of soils and loss of nutrients. The implication is that as the resource becomes scarce, more land will be opened up to harvest fuelwood and expansion of more lands for agriculture and settlement purposes. This causes the spreading of degradation as humans move to exploit forest resources which have been made easier with transportation networks (Figure 1). Thus, there were increasing concerns that fuelwood harvesting would ultimately exceed production rates, which could in turn result in the impoverishment of fuelwood-dependent communities (Wessels, Colgan, Erasmus, Asner, Twine, Mathieu, Van Aardt, Fisher & Smit, 2013; Amoah, Marfo, & Ohene, 2015).

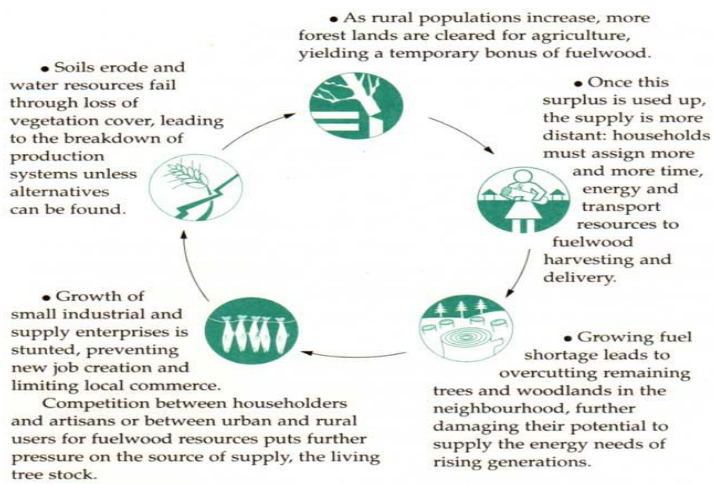

Figure 1: Fuelwood Demand and Diminishing Resources (Adopted from FAO, 2010)

Over the past several decades a considerable body of literature had emerged questioning and discrediting the scientific validity of fuelwood collection as a significant cause of forest loss (Leach and Mearns, 2013; Specht, Pinto, Albuqueque, Tabarelli, & Melo, 2015). These critics argue that after over a century of concerns, the supposedly imminent fuelwood crisis has yet to occur. And that fuel collectors rarely fell large trees, thus complicating a variety of assumptions about fuelwood collection practices. This shows that, fuelwood collection forms part of the utilization of already fallen trees from other activities as a result of land use shift, majorly agriculture (Arnold & Persson, 2003; Kerr, 2005; San, Spoann, Ly, & Chheng, 2012; Specht et al., 2015; Nuberg, 2015; Bhatt,Moanaro,& Sarkar, 2017; Nott & Thondlana, 2017; Simon& Peterson, 2018; Mohammed, 2021).

This paper seeks to investigate if the major fuelwood source regions in Nigeria's drylands identified by Mohammed and Tanko (2018): Falgore Game Reserve (Kano state), Dukku Forest Reserve (Gombe state) and Rafin Chiyawa Forest Reserve (Bauchi state) conform to the Fuelwood Gap Theory, with objectives of examining the vegetation cover of the source regions and identifying the major activities at the regions.

Study Area

The study area covers different three forest reserves: Dukku Forest Reserve, Falgore Game Reserve, and Rafin Chiyawa Forest Reserve.

Dukku forest reserve lies within the Dukku Local Government Area of Gombe State, Nigeria (Figure 2). The Gongola River flows through the west and north of the LGA. It has an area of 3,815 km². The hot season lasts for 2-3 months, from early March to mid-May, with an average daily high temperature above 98°F. The cool season lasts for 3 months, from mid-July to early October, with an average daily high temperature below 87°F. Dukku experiences extreme seasonal variation in monthly rainfall. The rainy period of the year lasts for 7 months, from early April to late October. The common tree species found include *Anogeissusleiocarpus* (Marke.H), *Guiera senegalensis* (Sabara.H), *Vitellaria paradoxa* (kadanya.H), *Detariummicrocarpum*(Taura.H), *Tamarindus indica* (Tsamiya.H), *Sterculia setigera* (Kukkuki.H) and *Combretum nigricans* (Tsiriri, H.), (Mohammed, 2021).

Falgore Game Reserve formerly known as Kogin Kano Game Reserve is located in Doguwa LGA, Kano State, Nigeria (Figure 3). It has an estimated land area of 92,000 ha and is contiguous to Tiga artificial Lake to the north, and Lame Burra Game Reserve in Bauchi State to the Southeast (Yelwa, 2008). The mean annual rainfall in FGR is approximately 1000mm and decreases to about 800 mm as geographical space shift northwards to Kano Metropolitan (Olofin, 2000). Some common tree species include *Parkia biglobosa* (Dorawa, H.), *Lanneamicrocarpa* (Faru, H.), *Diospyros mespiliformis* (Kanya, H.), *Tamarindus indica* (Tsamiya, H.), *Mangifera indica* (Mangwaro, H.), *Cyperus articulates* (Turare, H.), *Anogeissusleiocarpus* (Marke, H.), *Pterocarpus erinaceus* (Madobiya, H.), *Detariummicrocarpum* (Taura, H.), *Isoberliniadoka* (Doka, H.) and *Combretum nigricans* (Tsiriri, H.) (Mohammed, 2021). The major land uses the game reserve serves include farming, rearing of animals, hunting, fuelwood collection, settlements and sand mining (Mohammed, 2021).

The Rafin Chiyawa Forest Reserve is over 280,000km^2 and comprises of two forest reserves namely; Batu and Jimi Jan Dutse Forest Reserves. It lies between latitude 10^0 49′North, 10^o 51′North and longitude 9^0 23′East, 9^0 25′East (Figure 4). It is found in Ningi LGA of Bauchi State in the North Eastern part of Nigeria. In terms of climate, it conforms to the Bauchi state two distinct seasons, dry season and rain season. There is six months of rain, beginning in May and ending in October. The farming season is from May to December , including the harvest period, which takes place between October and December (World Health Organization, WHO, 2006).There are two distinctive vegetation zones, namely, the Sudan savannah and the Sahel savannah.

The vegetation types are conditioned by the climatic factors, which in turn determine the amount of rainfall received in the area. For instance, the rainfall in the state ranges between 1,300mm per annum in the south and only 700mm per annum in the extreme north.

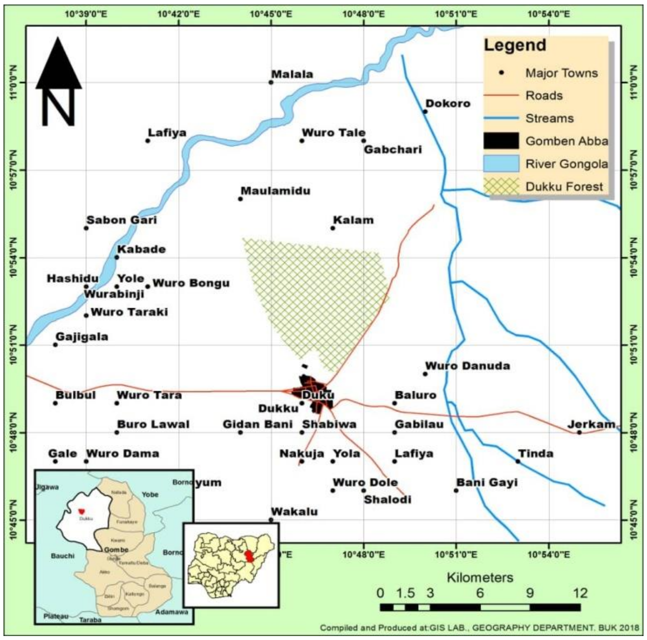

Figure 2: Dukku Forest Reserve

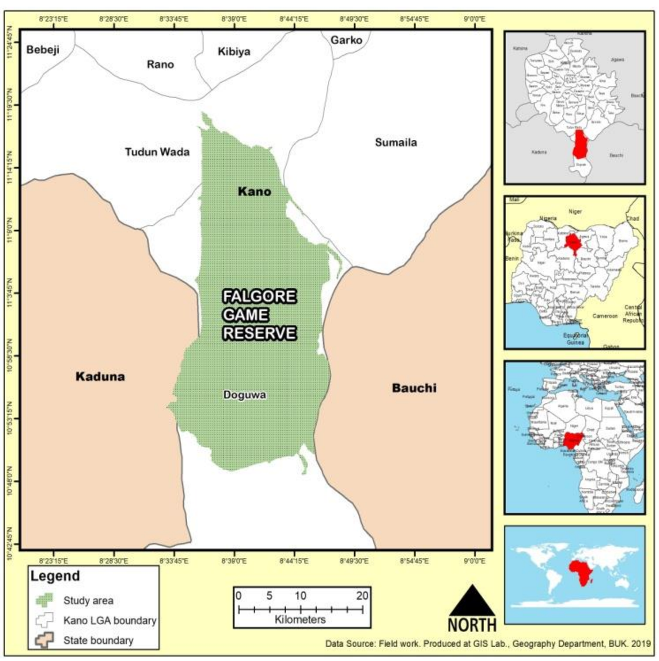

Figure 3: Falgore Game Reserve

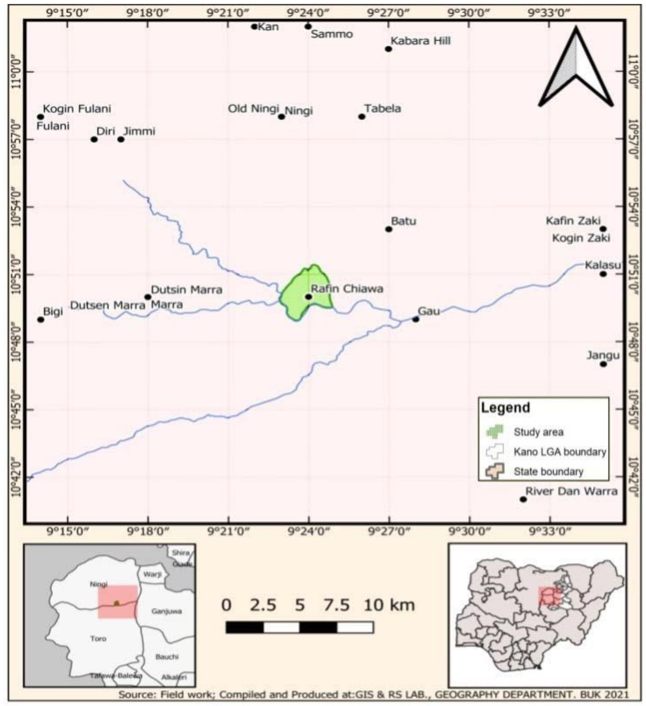

Figure 4: Rafin Chiyawa Forest Reserve

2. MATERIALS AND METHODS

To examine the vegetation cover at the forest reserves, Landsat images of the sites were subjected to maximum likelihood supervised classification method, accuracy assessment and post classification comparison of the classified maps. The images were downloaded from GLCF, unzipped and stacked in ENVI 5.1 software using bands 1 to 7; however, bands 4, 3 and 2 were the bands that were utilized for the analysis, that is where we have the infrared and near infrared bands that vegetation phenology is highest. The study sites were then subset from the stacked images using the shape files created from a 1966 base map of Nigerian forests (Figure 5), for all the different time periods. Gain and offset radiometric correction was then performed on all the subset images to improve their clarity for better visualization and interpretation before onward analysis. Some of the Landsat images (Gombe 2010, Kano 2010, Bauchi 2000 and 2010) had a scan line that had to be removed using the single file gap fill (triangulation) in ENVI software.

Maximum likelihood supervised classification technique was performed on the subset images. Ten training sites were taken for each land use type for all the images of the three forests identified. Google earth and field data served as ground truthing data for deriving regions of interest (ROI) for both the classification and accuracy assessment. During the classification, the subset images of some of the source regions (Dukku (2010) and Rafin chiyawa (2000)) had issues of missing information. Thus, the Dukku (2010) image was substituted with Dukku (2013) while for Rafin chiyawa only 1990, 2010 and 2018 were used for the classification and calculating class statistics. The image classification was done in Envi 5.1 environment. The images were classified based on Anderson, Hardy, Roach, and Witmer's (1976) land use land cover classification system. This was adopted because the criteria for this classification system are apt for the study sites as the levels and categories within the classes' description/ definition suit the characteristics of the study sites.

To identify the major activities and data on tree density at the source regions, transect walks, field measurements and personal observations were used, with the aid of tools such Global positioning system (GPS), audio recording device, camera, ranging poles, measuring wheel, measuring tape and writing materials. Three quadrats of 60m by 60m were established at each study site. The coordinates, density of trees, tree stumps and shrubs were taken on both farmlands and woodland (places of fuelwood) and recorded.

3. RESULTS AND DISCUSSION

Vegetation cover Analysis

From the maximum likelihood supervised classification of the Dukku Forest Reserve, Falgore Game Reserve and Rafin Chiyawa Forest Reserve images, six different classes were identified, that is Forest (F), water body (WB), woodland (WL), farmlands (FL), built-up (BUP) and bare surface (BS). The overall accuracy for all the classified maps was above 85%, in accordance with Anderson et al., (1976) scheme of classification criterion of the minimum level of interpretation accuracy in the identification of land use and land cover categories from remote sensor data that should be at least 85%. The PCC carried out among the pairs of classified maps 1990/2000, 2000/2010, 2000/2013, 2010/2018 and 1990/2018, for the Game and Forest Reserves were able to show the direction of change in the land use/cover of the compared periods and the matrix statistical table quantified the changes among the different land uses/cover. The results are discussed based on the three source regions identified.

Dukku Forest Reserve

From Table 1, the forest class mostly changed to bare surface by 31.72 km^2, woodland, 27.34 km^2 and farmlands 17.9 km^2, this signifies that the vegetation cover at the reserve experienced forest degradation from 1990 to 2000 owing to anthroogenic activities. The shaded parts show the areal extent of each class that remained unchanged between the periods compared.

Table 1: Matrix table for Dukku Forest Reserve 1990/2000

2000 LULC	**1990 LULC** Forest (km^2)	**Water body**	**Woodland**	**Built-up**	**Bare surface**	**Farmlands**
Forest	48.16	10.5	8.25	0.73	3.07	9.11
water Bodies	4.33	3.43	1.04	0.02	0.03	0.04
Woodland	27.34	3.41	1.28	0.68	3.12	1.02
built-up	13.72	1.13	0.44	2.49	8.15	0.56
Bare surface	31.72	2.55	1.2	7.5	31.11	1.23
Farmlands	17.9	2.4	1.13	0.34	3.4	2.25

Between 2000 and 2013 (Table 2), a similar scenario applies with the forest class mostly being converted to woodland, bare surface and farmlands showing that the vegetation cover further deteriorated between the periods.

Table 2: Matrix table of Dukku Forest Reserve 2000/2013

2013 LULC	**2000 LULC** Forest	**Water body**	**Woodland** (km2)	**Built-up**	**Bare surface**	**Farm lands**
Forest	23.7	2.47	13.55	8.04	15.27	10.86
Water bodies	1.1	1.36	1.29	0.01	0	0.14
Woodland	34.62	2.86	6.41	5.31	20.55	7.96
Built-up	0.09	0.01	0.03	1.81	0.72	0.02
Bare surface	13.85	1.78	12.15	11.01	38.08	6.98
Farmlands	6.44	0.41	3.42	0.33	0.69	1.45

The forest cover in Table 3 was mostly converted to farmlands by 33.77 km^2, thereby making the water body more visible with a change of about 18.55 km^2 since there are no tree canopies to shield the water body from being captured by satellites.

Table 3: Matrix table of Dukku Forest Reserve 2013/2018

2018 LULC	2013 LULC Forest (km^2)	Water body	Woodland	Built-up	Bare surface	Farmlands
Forest	3.97	0.03	4.67	0	1.14	0.47
Water bodies	18.55	3.21	13.47	0.06	3.9	4.99
Woodland	3.77	0.28	5.67	0.01	0.19	5.2
Built-up	4.48	0.01	1.31	1.96	12.28	0.06
Bare surface	9.36	0.06	6.15	0.6	35.17	0.4
Farmlands	33.77	0.31	46.43	0.04	31.17	1.61

For the pair 1990/2018 (Table 4), the forest cover was significantly lost to farmlands (67.25 km^2), depicting forest degradation on a general basis in **s**pite of the coverage area converted to woodland and the exposed water body.

Table 4: Matrix of Dukku Forest Reserve 1990/2018

2018 LULC	1990 LULC Forest (km^2)	Water body	Woodland	Built-up	Bare surface	Farmlands
Forest	5.82	1.31	1.65	0.03	0.61	0.85
Water body	25.59	7.03	3.89	0.58	2.12	4.98
Woodland	10.96	0.42	1.78	0.1	0.3	1.57
Built-up	10.03	1.57	0.26	2.09	5.64	0.5
Bare surface	23.52	4.29	0.97	2.98	17.3	2.68
Farmlands	67.25	8.8	4.79	5.97	22.89	3.63

For the pair 1990/2000 of the PCC, there was a decline in the forest and water body, whereas there were increases in the other land uses/cover, with the highest in bare surface (Table 5). For 2000/2013, the forest and water body classes decreased, though not as much as that of 1990/2000 period, while there was significant increase in the woodland class, this could be associated with regeneration. The built up area and farmlands decreased during this period (Table 6). Between 2013 and 2018, the forest and woodland classes decreased, with an increase in farmlands (Table 7). For the pair 1990/2018, there have been a positive change in all the classes identified except for the forest cover. The decrease in forest class and low positive value of the woodland cover signifies that the Dukku Forest Reserve has experienced a sigificant degradation from 1990 to 2018, as a result of other human activities apart from fuelwood collection such as opening up more lands for agricultural activities, road construction and sand mining, as evidently seen during the ground truthing exercise. Thus, it can be concluded that Dukku Forest Reserve deteriorated from 1990 to 2018, not as a result of fuelwood collection as speculated rather other anthropogenic activities such as clearing land for agricultural activities.

Falgore Game Reserve

In Table 5, the forest class was mostly changed to woodland and built-up classes between 1990 and 2000, a pointer to the fact that the richness of the vegetation cover declined, though not as much as that observed in Dukku Forest Reserve for the same period.

Table 5: Matrix of Falgore Game Reserve 1990/2000

2000 LULC	1990 LULC Forest (km^2)	Water body	Woodland	Built-up	Bare surface	Farmlands
Forest	21.01	3.18	3.37	4.88	0.01	66.64
Water body	9.21	4.15	7.25	5.34	0.27	57.49
Woodland	15.54	5.8	6.47	58.78	5	161.15
Built-up	12.48	10.49	5.19	144.41	71.7	128.29
Bare surface	0.97	0.69	0.58	32.82	11.87	26.85
Farmlands	0.93	2.41	0.48	56.59	36.29	29.79

For the pair 2000/2010 (Table 6), 23.65 km^2 of the forest class was converted woodland, exposing more of the water body that must have been shadowed by the forest cover in the earlier years.

Table 6: Matrix of Falgore Game Reserve 2000/2010

2010 LULC	**2000 LULC** **Forest**	**Water body**	**Woodland**	**Built-up** (km^2)	**Bare surface**	**Farmlands**
Forest	59.46	58.65	140.52	92.46	16.12	9.32
Water body	15.41	6.97	2.95	2.35	0.03	0
Woodland	23.65	16.15	66.78	22.98	6.09	0.78
Built-up	0.42	1.11	15.04	98.15	17.12	37.72
Bare surface	0.02	0.34	9.8	109.71	21.11	60.83
Farmlands	0.12	0.5	17.66	46.91	13.31	17.82

Between 2010 and 2018 (Table 7), the degradation of the vegetation of Falgore Game Reserve was more severe than in the 2000/2010 pair, more than 100km^2 of the forest class has been changed to woodland as against 32km^2 in the 2000/2010 period.

Table 7: Matrix of Falgore Game Reserve 2010/2018

2018 LULC	2010 LULC Forest (km^2)	Water body	Woodland	Built-up	Bare surface	Farmlands
Forest	143.2	10.89	49.63	16.02	3.05	10.71
Water body	51.25	13.47	21.41	1.46	0.5	0.69
Woodland	102.05	3.21	49.14	5.28	0.1	2.96
Built-up	20.81	0.08	5.1	50.77	23.07	16.95
Bare surface	56.15	0.06	11.09	85.73	163.71	60.3
Farmlands	3.07	0	0.06	10.29	11.39	4.7

Table 8: Matrix of Falgore Game Reserve 1990/2018

2018 classes	1990 classes Forest (km^2)	Water body	Woodland	Built-up	Bare surface	Farmlands
Forest	30.56	7.96	7.21	43.36	6.22	138.19
Water body	15.45	5.18	5.81	9.52	0.55	52.27
Woodland	7.2	3.25	6.16	29.42	0.48	116.25
Built-up	2.23	2.92	1.57	55.01	22.26	32.8
Bare surface	4.08	6.98	2.53	154.15	91.89	117.41
Farmlands	0.62	0.42	0.06	11.37	3.76	13.29

For the period 1990/2018 (Table 8), the forest class did not change much to other classes, rather increased from the farmland class that lost 138km^2 of land to the forest class. This can be attributed to insurgency and other forms of insecurity in the Nigerian forests that have been reported to have claimed properties, towns and villages (Ladan 2014; Ladan, 2015; Apanshan, Ismail,& Zengeni, 2017; Abubakar,Yusof,& Azlilan, 2018; Mohammed& Tanko, 2018). Olaniyan (2018) reported that Falgore Game Reserve and Gomo community have become a nightmare for residents of the Doguwa, Sumaila, Tudun Wada and Kibiya communities due to escalating rates of kidnapping perpetrated by people operating from deep within the forests.

The temporary clearing of land by nomadic Fulani during sedentary camping helps to explain the fluctuations in the built-up class reported by Badamasi (2014). For 1990/2018, forest, woodland and bare surface classes all increased and the water body more exposed, while the built-up area and farmlands plummeted (Table 9). Hence, for the period under study, the vegetation cover of the Falgore Game Reserve increased. Although, access and availability of fertile soil for agriculture has been reported to have influenced the demographic characteristic of the area especially population growth and immigration in the past. For instance, with resettlement of old Falgore town from the heart of the forest to its current location made the area to witness a geometric growth of more than 300% (Badamasi, 2014).

Rafin Chiyawa forest reserve

In (Table 9), 234.57 km^2 of the forest land was converted to the farmlands class, and about 40km^2 to bare surface and built-up classes.

Table 9: Matrix of Rafin Chiyawa Forest Reserve 1990/2010

2010 classes	1990 classes Forest (km^2)	Water body	Woodland	Built-up	Bare surface	Farmlands
Forest	83.95	15.67	26.82	90.54	8.83	10.9
Water body	9.34	18.09	2.52	18.59	0.19	0.11
Woodland	12.79	12.02	76.39	103.26	1.59	1.84
Built-up	23.62	16.1	136.21	128.15	1.59	1.84
Bare surface	25	3.8	95.84	123.02	121.44	27.46
Farmlands	234.57	24.29	295.73	493.84	236.71	151.75

More than 100km^2 of the forest land was converted to bare surface and built-up class between 2010 and 2018 (Table 10). Thus, there has been a significant reduction of the vegetation cover as a result of anthroogenic activities.

Table 10: Matrix of Rafin Chiyawa Forest Reserve 2010/2018

2018 classes	2010 classes Forest (km^2)	Water body	Woodland	Built-up	Bare surface	Farm lands
Forest	85.81	7.23	39.11	39.11	114.65	398.46
Water body	17.42	11	9.3	23.72	6.33	67.48
Woodland	8.93	0.22	1.27	3.03	0.12	19.68
Built-up	80.4	29.58	135.88	140.73	58.85	351.29
Bare surface	52.88	4.09	21.24	21.92	183.66	428.86
Farmlands	9.61	0.56	2.65	2.65	155.09	280.18

From 1990 to 2018, the forest cover at Rafin Chiyawa Forest Reserve decreased as a result of population increase as shown by the change of the foresrt class to built up and opening up of more land for agricultural activities (Table 11). This is consistent with what was observed during the ground truthing exercise at the forest reserve, where most of the land has been converted to sesame, guinea corn fields and settlements within the Reserve.

Table 11: Matrix of Rafin Chiyawa Forest Reserve 1990/2018

2018 classes	1990 classes Forest (km2)	Water body	Woodland	Built-up	Bare surface	Farmlands
Forest	142.69	24.92	181.57	237.79	43.01	35.29
Water body	18.49	22.27	34.82	41.17	7.58	7.79
Woodland	12.6	1.27	4.1	10.83	0.83	2.49
Built-up	85.54	32.48	294.12	336.55	17.01	14.72
Bare surface	75.1	5.79	92.22	234.07	172.13	52.71
Farmlands	54.84	3.23	26.67	96.98	132.91	80.85

Amongst the three study sites, Dukku Forest Reserve stands out to be the most degraded compared to Falgore Game Reserve and Rafin Chiyawa Forest Reserve. This can be owed to that fact that, amongst all three, Dukku forest reserve was the safest security wise, thereby making it more porous and vulnerable to human interference. Falgore Game Reserve has always been associated with criminal activities, in terms of armed robbery, hide out of criminals and of most recent insurgency and kidnapping activities. Rafin chiyawa Forest Reserve was also associated with these activities as deduced from transect walks with the forest extension workers of the Reserve. From the long transect walks and interviews done with forest extension workers and police men (in the case of Falgore Game Reserve) during the field survey (2018), these activities are quite active and still trying to regain normalcy.

Inventory of Trees and Shrubs at Falgore Game Reserve (FGR)

From Table 12, the woodland quadrats have more trees (76%) in them as against farmland quadrat with the same percent of tree stumps (7%) and standing trees (7%). Therefore, the farmland sets in more degradation than other uses of fuelwood collection, lumbering and rearing of animals.

Table 12: Inventory of Trees, Shrubs and Tree stumps on Woodlands and Farmlands at FGR

	Woodland1			**Woodland2**			**Farmland**		
	N	**Density**	**%**	**N**	**Density**	**%**	**N**	**Density**	**%**
Trees	94	0.026	48	89	0.025	28	3	0.001	7
Tree Stumps	3	0.001	2	6	0.002	2	42	0.001	7
Shrubs	98	0.027	50	220	0.061	70	3	0.012	86
Total	195	0.054	100	135	0.088	100	48	0.014	100

Inventory of Trees and Shrubs at Dukku Forest Reserve (DFR)

From Table 13, the woodland quadrats have more trees (61%), as against farmland quadrat with more tree stumps (96%) than standing trees (4%). Thus, the farmland will subject the reserve to more degradation than other uses that the reserve is being subjected. The same applies for the shrubs, just as the case of the Falgore Game Reserve.

Table 13: Inventory of Trees, Shrubs & Tree Stumps on Woodlands and Farmlands at DFR

	Woodland 1			**Woodland 2**			**Farmland**		
	N	Density	%	N	Density	%	N	Density	%
Trees	191	0.054	24	59	0.016	37	15	0.001	4
Tree stumps	47	0.013	6	30	0.008	19	95	0.026	96
Shrubs	560	0.156	70	69	0.019	44	0	0	0
Total	798	0.223	100	158	0.043	100	110	0.027	100

Inventory of Trees and Shrubs at Rafin Chiyawa Forest Reserve

The farmlands in Rafin Chiyawa Forest reserve were completely devoid of any trees and shrubs, but completely covered with sesame and guinea corn. Table 14 reflects the inventory on number trees, shrubs and tree stumps for the reserve.

The major land uses observed at the reserves were farmlands, fuelwood collection, settlements, cattle rearing and sand mining. Other activities included timber extraction for construction purposes and crafts. Trees are also being cleared by Fulani nomads whom have settled. According to the forest workers, plots of land were given out by the local heads of the villages and towns, like *Sarkin Dukku*, whom has access to about 500-1000m^2 of land and *Sarkin Gombe* having more than 3,000m^2 of land, in whose hands the ownership of the forest land has been invested (Local government councils), while the state governments retain the responsibility of protecting and managing the forest reserves under the Local governments reform act of the land use act of 1978. As at the time of field visit (2018), about 112 persons have been approved to be given pieces of land within the reserve for agricultural activities.

Table 14: Inventory of Trees, Shrubs and Tree stumps on Woodlands & Farmlands at RFR

	Woodland 1			**Woodland 2**			**Rocky Outcrop**		
	N	Density	%	N	Density	%	N	Density	%
Trees	43	0.013	37	56	0.016	34	47	0.012	48
Tree stumps	7	0.003	9	4	0.001	2	9	0.002	8
Shrubs	39	0.019	54	107	0.03	64	70	0.011	44
Total	89	0.035	100	167	0.047	100	126	0.025	100

The ring of deforestation and degradation is thus circular, moving outwards from the Kano metropolis extending to forests in other parts of Nigeria's drylands, though not owing to fuelwood collection alone but also agriculture and sand mining among others. From the study sites, the fuelwood supply follows forests already exposed to degradation in a circular pattern from majorly agricultural expansion. It has similarly been reported that deforestation due to conversion of forests to agricultural land, accounts for almost 80 percent of the world's forest loss, while weak governance, lack of tenure rights for local communities and poverty are underlying drivers which can lead to unsustainable use of forests (Cooke St Clair, 2011; FAO, 2016; FAO, 2017). This is a true reflection of what was observed at all three sites under study.

The movement of fuelwood collection outwards at 26km, 200km and 400km from the formally Kano closed settled zone, traveled to source for fuelwood that coincides with the source regions earlier established from literature (Nicol, 1989; Cline-Cole,Falola, Main, Mortimore, Nichol, and O'Reilly, 1990; Mortimore, 1998; Mohammed &Tanko, 2018), disputes the Fuelwood Gap Theory because it does not take cognizance of the role of agricultural land expansion as the driving force in setting in forest degradation rather than fuelwood consumption (Figure 4). Thereby, the theory can only stand if it accommodates forest land lost to agriculture within the realms of the theory. Thus, fuelwood collection forms part of the utilization of already fallen trees from agriculture (San et al., 2012; Specht et al.,2015; Simon & Peterson, 2018; Mohammed, 2021). Specht et al., (2015) were of the opinion that less emphasis has been given to deforestation due to land use shifts, such as agriculture that sets the pace for degradation while the bye-product is utilized as fuelwood.

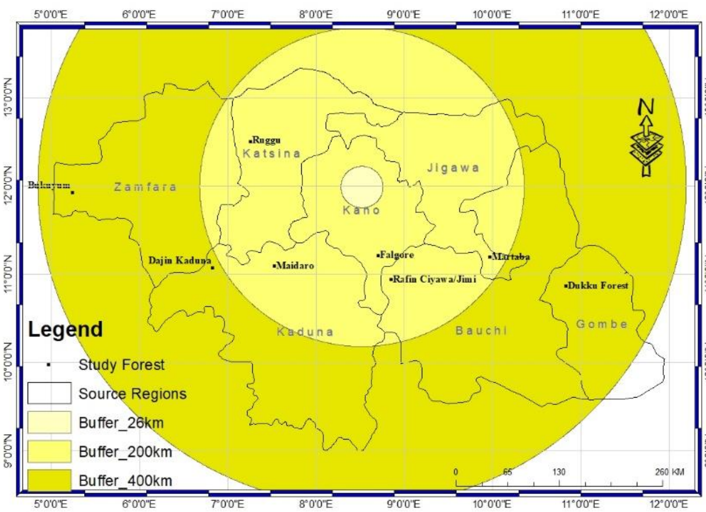

Figure 4: Rings of degradation along fuelwood source regions

A study conducted in 55 villages of the farmed parkland landscape of Kano region Nigeria, showed a self-sustaining and stable system in terms of tree densities, even inthe face of rapid population growth (Usman& Nicol, 2019). Commercial agricultural expansion has been said to account for two-third of forest resource degradation in Latin America while subsistence agriculture expansion accounts for one third of deforestation in tropical and sub-tropical Africa and Asia (Arnold & Perez, 2001; Suleiman, Abdul-Rahim, Chin, and Mohd-Shahwahid, 2017). The fuelwood gap Theory has been considered to be probably too simplistic, because such relationships between fuelwood collection, per se, and deforestation may be very location specific and not a general problem (Arnold & Persson, 2003; Nuberg, 2015; Parker, Keenlyside, Galt, Haupt,and Varns, 2015).

In practice, fuelwood has also been sourced from scrub, bush fallow, farm trees and the likes-and most of these could regenerate and are regenerating, whereas the supply estimates were mostly based on stock and yield figures relating to forest resources. Thereby, making such estimates cannot hold for the actual supply situation of fuelwood. Reappraisal of the data for some individual countries using more realistic assumptions showed potential surpluses rather than deficit. The most important from the careful investigation of the actual supply patterns was that the fuelwood coming from felling of trees was on land being cleared for agriculture, thus, the major cause of deforestation (Foley, 1987; Arnold & Perssons, 2003; Odihi, 2003; Mohammed, Idris &Tanko, 2019). According to Broadhead (2016) the calculations upon which the crisis was founded were, however, faulty and failed to account for fuel switching with income growth or collection of fuelwoods from outside designated forest areas, which formed the basis of supply estimates. As such, the crisis forecast did not occur.

Throughout Africa and Asia, especially within dryland forests, colonial foresters expressed concern that biomass was being harvested at unsustainable rates. Perhaps, this forest exploitation was due in large part to industrial scale charcoal production which powered railroads used to procure resources for colonial interests. Many of these foresters also falsely interpreted arid landscapes as already degraded by excessive forest use by locals, despite historical records pointing to a much different land cover history (Simon & Peterson, 2018).

Over the past several decades a considerable body of literature had emerged questioning and discrediting the scientific validity of fuelwood collection as a significant cause of forest loss (Leach and Mearns, 2013; Specht et al.,2015). These critics argued that after over a century of concerns, the supposedly imminent fuelwood crisis has yet to occur. They stated that fuelwood collectors rarely cut down large trees, thus complicating a variety of assumptions about fuelwood collection practices.Nott and Thondlana (2017)observed the high regeneration abilities of many fuelwood sources, opining that much fuelwood collection was in fact largely sustainable. Large trees were usually cut down to open up agricultural lands and for lumbering. This poses more of a threat than fuelwood collection on the Reserves, where degradation indices, such as erosion has set in and ultimately loss of soil fertility and compactness that could cause a decline in agricultural productivity in the face of increasing population (Patel,Pinckney, and Jaeger, 2006). This is also the case in the three sites visited.

CONCLUSION

The Fuelwood Gap Theory comes off short because it has neglected forest clearance from farmlands that makes fuelwood available for consumption, as evidenced from the Game and Forest Reserves that serve as fuelwood source regions investigated. The theory could have sufficed if it had assumed trees lost to agricultural land equates to forest land degraded within its confines. Thus, fuelwood consumption cannot be seen as the main actor that leads to deforestation and ultimately forest degradation in the identified source regions.

RECOMMENDATIONS

The Fuelwood Gap Theory could be modified to look at forest degradation from a fuelwood consumption-agricultural activities nexus. This will encourage researches that look at the impact of deforestation as it relates to opening up of more forest land for agricultural activities.

The Government and other stakeholders should make available affordable energy alternatives, such as efficient cooking stoves, biogas, solar energy and the likes. This will go a long way in reducing the pressure on forest resources for energy.

Adoption of agroforestry for fuelwood collection and agricultural intensification that would be more sustainable by reducing pressure on harvesting wood from natural tree stands through increasing wood supply on farms, thereby greatly reducing pressures on forest reserves and at the same time improve food security and income generation.

Fuelwood consumption should not be perceived as a problem, rather be treated as an important sub-sector which needs to be developed. Wood energy development should be integrated into rural energy supply strategies and pursued as a common task for all relevant sectors, e.g. agriculture, forestry, rural development, energy and industry sectors.

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