Federal Republic of Nigeria

REVISED NATIONAL FOREST REFERENCE EMISSION LEVEL (FREL) FOR THE FEDERAL REPUBLIC OF NIGERIA

Federal Department of Forestry,
Federal Ministry of Environment

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List of Acronyms

AD	Activity Data
AGB	Aboveground Biomass
BGB	Belowground Biomass
CO2	Carbon dioxide
CP	Conference of the Parties
DCC	Department of Climate Change
EF	Emission Factor
FAO	Food and Agriculture Organisation of the United Nations
FME	Federal Ministry of Environment
FORMECU	Forestry Management and Evaluation Coordinating Unit
FRA	Global Forest Resources Assessment
FREL	Forest Reference Emission Level
FRL	Forest Reference Level
FRIN	Forestry Research Institute of Nigeria
GFOI	Global Forest Observations Initiative
GHG-I	Greenhouse gas Inventory
IPCC	Intergovernmental Panel on Climate Change
LULUCF	Landuse, Landuse Change and Forestry
MCCF	Ministry of Climate Change and Forestry
MRV	Measurement, Reporting and Verification
NAGIS	Nasarawa State Geographic Information Services
NAMA	Nationally Appropriate Mitigation Actions
NASRDA	Nigerian Air Space Research and Development Agency
NDC	Nationally Determined Contribution
NESREA	National Environmental Standards & Regulations Enforcement Agency
NFI	National Forest Inventory
NFMS	National Forest Monitoring System
SAE	Stratified Area Estimate
SEPAL	System for Earth Observation Data Access, Processing and Analysis for Land Monitoring
SLMS	Satellite Land Monitoring System
UNFCCC	United Nations Framework Convention on Climate Change

Executive Summary

The Federal Republic of Nigeria submits this Revised Forest Reference Emission Level (FREL) in accordance with Decision 12/CP.17 under the United Nations Framework Convention on Climate Change (UNFCCC). The revised FREL represents Nigeria's benchmark for assessing future emissions reductions from deforestation and forest degradation under the REDD+ framework.

The revised FREL is national in scope and covers the reference period 2017–2021. It is constructed following a stepwise approach, reflecting improvements in data availability, methodological rigor, and national technical capacity since Nigeria's first national FREL submission in 2019.

Compared to the previous FREL, the revised submission incorporates several methodological enhancements. These include the expansion of REDD+ activities to include forest degradation, the application of a systematic national sampling design for activity data generation, strengthened quality assurance and quality control procedures, and the inclusion of non-CO_2 gases (CH_4 and N_2O) associated with fire-related forest degradation. These improvements provide a more comprehensive and accurate representation of forest-related emissions in Nigeria.

Activity data were generated using a sample-based area estimation approach implemented through the Collect Earth platform, supported by high-resolution satellite imagery and a rigorous multi-tier QA/QC framework. Emission factors were derived from Nigeria's National Forest Inventory (NFI), which remains the most comprehensive nationally representative source of forest biomass data. To ensure methodological consistency and comparability with the previous submission, the same NFI dataset and emission factor derivation approach were retained.

The revised FREL includes emissions from deforestation and forest degradation. Enhancement of forest carbon stocks was not included, as the sampling intensity achieved during data collection was insufficient to robustly estimate afforestation, reforestation, and regrowth at the national scale. Regrowth observations are reported transparently but excluded from emission and removal estimates to avoid underrepresentation and potential bias.

Based on the aggregation of annual emissions from deforestation and forest degradation over the reference period, Nigeria's revised Forest Reference Emission Level is estimated at **58,403,033 tCO_2e per year**. This value represents the average annual forest-sector emissions for the period 2017–2021 and constitutes Nigeria's benchmark emission level for assessing future performance under the UNFCCC REDD+ mechanism.

Differences between the revised FREL and the previous submission primarily reflect methodological refinements, expanded activity coverage, and improved detection of forest change, rather than changes in underlying deforestation dynamics. The revised FREL therefore enhances transparency, completeness, consistency, and accuracy, in line with UNFCCC and IPCC guidance, and provides a robust foundation for future results-based payments and continued improvement of Nigeria's forest monitoring system.

1. Introduction

1.1. Background and Purpose of the FREL

The Forest Reference Emission Level (FREL) serves as a benchmark for assessing the effectiveness of policies and measures aimed at reducing emissions from deforestation and forest degradation.

The Federal Republic of Nigeria welcomes the invitation to submit a revised Forest Reference Emission Level (FREL) on a voluntary basis as expressed in Decision 12/CP.17, paragraph 13. This FREL submission is in the context of results-based payments for the implementation of reducing emissions from deforestation and forest degradation, and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks (REDD+) under the United Nations Framework Convention on Climate Change (UNFCCC).

The government has followed the guidance provided by the UNFCCC through the decisions taken at the Conference of the Parties (CP), notably the modalities for forest reference emission levels and forest reference levels in Decision 12/CP.17 and the guidelines for submission of information on reference levels in the Annex of Decision 12/CP.17.

The Government intends to take a step wise approach to its revised national FREL development as stated in Decision 12/CP.17, paragraph 10. As such, the current FREL reflects the best available information at the time of submission at national level. The scope and methodologies applied can be modified whenever improved data becomes available; and considering the previously submitted national FREL. The historical period considered, and/or the construction approach could also be revised.

For Nigeria, the FREL is a crucial component of the country's strategy to meet its Nationally Determined Contributions (NDCs) under the Paris Agreement. The revision of the FREL reflects Nigeria’s commitment to improving the accuracy and reliability of its forest-related emissions data.

1.2. FREL development Process

Nigeria's FREL development has progressed through an iterative process aligned with UNFCCC guidelines and the country's growing technical capacities in forest monitoring.

The process started with the development of a sub-national FREL for Cross River State (REDD+ pilot state) which was submitted to the UNFCCC for technical assessment in 2018. This initial effort provided valuable experience in compiling activity data, establishing emission factors, and applying transparent methodologies within the national context.

Building on the lessons and frameworks established at the sub-national level, Nigeria developed and submitted its first national FREL to the UNFCCC in 2019. This national FREL upscaled the Cross River State methodology to cover all ecological zones of the country, incorporating nationally relevant datasets and ensuring methodological consistency.

As part of Nigeria's commitment to continuous improvement, the country initiated the development of a revised national FREL. This revision incorporates updated datasets, improved land-use change assessments and strengthened methodological approaches.

The revised FREL has been supported through technical collaboration with Landell Mills under the Climate Action Africa programme funded by Global Affairs Canada, with additional technical support from the Food and Agriculture Organisation of the United Nations (FAO). These partnerships contributed to enhancing national capacity and improving data quality and ensuring that the revised FREL reflects international best practices and national priorities.

Throughout the process, Nigeria has maintained a participatory and consultative approach, engaging federal and state institutions, technical experts, academia, civil society to ensure that the process is transparent and robust.

1.3. Importance of FREL for Nigeria's Climate Strategy

Nigeria's forests are vital to the nation's environmental and economic wellbeing. They provide essential ecosystem services, including carbon sequestration, biodiversity conservation, and support for livelihoods. Given the ongoing pressures on forest resources from agricultural expansion, logging, and other land-use changes, establishing an accurate and credible FREL is fundamental for tracking progress in emission reductions and for securing international support through mechanisms such as REDD+.

1.4. Overview of the Revised FREL

The revised FREL for Nigeria includes activities related to deforestation and forest degradation. This revision represents a significant improvement over previous submissions by incorporating more comprehensive data, refined methodologies, and broader coverage of forest activities. The revised FREL aims to provide a more accurate representation of Nigeria's forest carbon dynamics, contributing to more effective climate mitigation efforts.

1.4.1. Objectives of the Revision

The primary objectives of the revised FREL are:

i. To enhance the accuracy and transparency of forest related emissions estimates.
ii. To incorporate additional activities such as forest degradation.
iii. To align the FREL with the latest IPCC guidelines and national circumstances.
iv. To support Nigeria's efforts in achieving its NDC targets and contributing to global climate goals.

1.4.2. Coverage

The revised FREL coverage is **national** consistent with Nigeria's **2019 national FREL**. Nigeria has a total land area of approximately **923,768 km² (about 92.4 million hectares)** as reported in the assessment of vegetation and land use changes in Nigeria (FORMECU, 1998), encompassing a wide range of ecological conditions and land-use systems.

1.4.3. Timeframe and Reference Period

The reference period for the revised FREL is from 2017 to 2021. This period was selected to provide a comprehensive understanding of the trends in deforestation and forest degradation over time, allowing for a more accurate projection of future emissions and removals. The updated reference period for Nigeria's Forest

Reference Emission Level (FREL) now includes data from 2017 to 2021, replacing the initial reference period of 2006 to 2016. This shift aligns with the latest data availability and improved satellite imagery, such as Planet NICFI, Sentinel-2, providing more accurate and recent insights into land use and deforestation trends. Nigeria has selected this new period to adhere to updated international guidance, ensuring consistency with both the Forest Carbon Partnership Facility (FCPF) methodological framework and the GCF scorecard. This new 5-year reference period allows for a better reflection of current deforestation dynamics and strengthens the credibility of Nigeria's forest emission reporting.

2. National Circumstances

2.1. Geographic and Environmental Context

Nigeria's national circumstances characterized by diverse ecological zones ranging from humid tropical forests to semi-arid savannas, and by significant variations in climate, soils, and land-use pressures continue to shape both the dynamics of deforestation and the methods applied in estimating emissions. In this revised FREL, these biophysical realities inform several methodological updates, including the stratification of the country into ecological zones for activity data generation, the use of improved satellite datasets that better capture land-cover transitions across heterogeneous landscapes, and the refinement of emission factors to reflect ecological variability in biomass stocks. The updated methodological approach therefore builds on the national circumstances previously described in the 2019 FREL, while integrating enhanced datasets and analytical tools to more accurately represent Nigeria's forest-related emissions.

2.2. Overview of Ecological Zones and Forest Types in Nigeria

For the purposes of estimating Emission Factors (EFs) in this revised FREL, the ecological zones were grouped following the same stratification approach used in the 2019 national FREL which is based on similarities in their biophysical characteristics, vegetation structure, and available biomass data. Mangrove and Freshwater Swamp forests were combined because both represent wetland forest ecosystems with comparable hydrological regimes, species assemblages, and allometric behaviour, and because national forest inventory data for these zones are often aggregated due to their geographic contiguity in the Niger Delta. Similarly, the Sudan and Sahel Savanna zones were merged for EF estimation, as both share open woodland to shrubland vegetation types, low biomass densities, and comparable climatic conditions that influence carbon stock levels.

These groupings ensure methodological consistency, reduce uncertainty associated with sparse plot data in individual zones, and align with the stratification approach used in the 2019 national FREL. As the detailed descriptions of each ecological zone were comprehensively presented in the 2019 FREL submitted to the UNFCCC, they are not repeated here. Readers are referred to that document for the full ecological characterisation, while this revised FREL focuses on methodological updates and improved data inputs relevant to emission factor development.

The socio-economic factors influencing forest dynamics in Nigeria include population growth, agricultural practices, energy demand, and economic policies. The dependence on fuelwood and charcoal for energy, particularly in rural areas, exacerbates deforestation and forest degradation. Additionally, the expansion of agriculture, driven by the need to feed a growing population, has led to the conversion of forests to cropland.

2.3. Institutional Framework and Governance

Forest governance in Nigeria is managed by various government institutions at the federal, state, and local levels. The Federal Ministry of Environment, through its Forestry Department, is responsible for national forest policies and international reporting, including the FREL. State governments manage forest resources within their jurisdictions, developing state forestry policies and enforcing regulations, though the effectiveness varies across states. In some REDD+ pilot states, participatory land use planning has been introduced at the community level to support sustainable resource management and reduce pressures on forests. The revised FREL reflects the efforts of these institutions to improve forest management and contribute to national climate goals.

2.4. Definition of Forest and Forest Land

Nigeria's definition of forest follows the national forest definition applied in the previous FREL submission and remains unchanged. Forest is defined as a*n ecological community predominated by trees and other layers of woody plants with a minimum area of **0.5ha**, a minimum tree height of **3metres**, and a minimum tree canopy cover of **15%**, or stands with potentials to reach the above thresholds in situ.*

This definition applies nationally and is used consistently for the FREL, the national greenhouse gas inventory, and future reporting under the UNFCCC.

Further details on the consultations and processes undertaken to arrive at the forest definition were detailed in the sub-national FREL submitted by Nigeria to UNFCCC in January 2018.

2.5. Relevant Policies and Plans

Nigeria's Forest Reference Emission Level (FREL) is developed within the context of existing national policies, legal instruments, and institutional frameworks that guide forest management, land use, and climate governance. These instruments provide the enabling environment for forest governance and climate action. The construction of the FREL itself, however, remains a technical exercise based exclusively on historical activity data, emission factors, and IPCC guidance, and is not influenced by policy targets or implementation measures.

Forest governance in Nigeria is guided by the National Forest Policy, which promotes sustainable forest management, conservation of forest resources, and improved governance of forest lands across federal and state levels.

Nigeria's engagement in REDD+ is coordinated through the National REDD+ Strategy, which identified drivers of deforestation and forest degradation and outlined strategic responses. The strategy provides contextual information for interpreting forest-sector trends but does not influence the construction, scope, or numerical values of the FREL.

National climate governance is anchored in the Climate Change Act, which establishes the institutional framework for climate coordination and reporting in Nigeria. While the Act supports transparency and institutional coordination, it does not prescribe methodological choices or affect the construction of the FREL, which is derived solely from historical data and IPCC-consistent methods.

The technical basis for forest monitoring, reporting, and verification is provided through Nigeria's National Forest Monitoring System (NFMS), including the National Forest Inventory (NFI). The revised FREL is aligned with this system to ensure consistency with national greenhouse gas inventory reporting and future transparency requirements under the UNFCCC.

3. Scope of the Revised FREL

3.1 Estimation of Historical Emissions

IPCC (GPG 2003 and Guidelines for National GHG Inventories in AFOLU, 2006) provides the framework for estimating emissions and removals of CO_2 in the AFOLU sector. Two basic inputs needed are Activity Data (AD: e.g. changes in areal extent of forest land (ha/year)) and emission factors (EF: e.g. emissions/removals of GHG per unit area: tCO2/ha of deforestation). The product of AD by EF produces an estimate of the amount of emissions/removals in a given year as a result of the activity. IPCC present three approaches (1-3) for estimating AD and three Tiers (1-3) for estimating EF. The estimation of historical emissions therefore requires estimates of historical activity data and emission factors.

3.2. Types of Activities Included

Forest degradation results in the loss of carbon stocks within the forest remaining forest category and can constitute a significant source of emissions. In line with the Cancun Agreement, REDD+ activities include the reduction of emissions from deforestation and forest degradation, among others.

In Nigeria's previous national FREL submitted in 2019, the scope of activities was limited to emissions from deforestation only. At the time, forest degradation arising from activities such as selective logging, fuelwood extraction, charcoal production, and forest fires was excluded due to limitations in reliable and consistent national-scale activity data and the absence of sufficiently robust emission factor information. The justification for this exclusion is documented in the 2019 FREL.

Building on the stepwise approach encouraged by the UNFCCC, and consistent with commitments made in the previous submission, Nigeria has expanded the scope of its revised FREL to include forest degradation. This expansion reflects improvements in data availability, methodological development, and national technical capacity, and enables a more comprehensive representation of forest-related emission sources, particularly in areas where biomass loss occurs without a complete land-use change.

3.2.1. Omission of enhancement of forest carbon stocks

Nigeria considers the REDD+ activity "enhancement of forest carbon stocks" to be both enrichment in carbon stocks in forest remaining forest, as well as enrichment in carbon stocks through afforestation/reforestation and natural regeneration of forest. The country has promoted natural forest restoration and plantation silviculture that leads to reduction in emissions from deforestation and forest degradation.

Nigeria's regrowth class definition includes both natural forest regrowth and afforestation and reforestation activities, and this category was included in the original survey design used for data collection. However, in the process of implementation, the applied sampling intensity was found to be insufficient to capture afforestation and reforestation activities in Nigeria during the proposed monitoring period and there are concerns that with the available imagery omissions of restoration in plots is common. A total of 16 sample points were identified as regrowth, all of which corresponded to natural forest regrowth. Consequently, Nigeria decided to exclude regrowth from the current FREL submission to avoid underrepresentation of enhancement of carbon stock in the country. Nevertheless, to maintain consistency with the original survey design and ensure transparency in reporting, these sample points are presented as a separate regrowth class in the activity data (AD). No emissions or removals are reported for this class in the current submission.

3.3. Pools included

While IPCC recognises five carbon pools: above ground (live tree) biomass, belowground (live tree) biomass, deadwood (standing and lying/down), litter, and soil organic carbon; only pools considered significant, consistent with the SBSTA decision adopted at COP17, need to be included. Hence, the soil organic carbon pool was omitted in this revised FREL, only above-ground biomass, below-ground biomass, litter, and deadwood were considered. Although the National Forest Inventory includes measurements of dead biomass, changes in deadwood and litter were excluded from the Emission Factors for forest degradation. This methodological choice ensures consistency with the Tier 1 assumption that dead organic matter pools in forest land remaining forest land are in steady state and avoids potential double counting with emissions from fire-related degradation, including non-CO_2 gases (CH_4 and N_2O), which are estimated separately.

3.3.1. Omission of soil organic carbon

Soil organic carbon (SOC) is recognised by the IPCC as an important forest carbon pool. However, as documented in Nigeria's 2019 national FREL, significant changes in SOC stocks generally occur only when forests are converted to non-forest land uses, and associated emissions are released gradually over extended time periods. As such, SOC responses are less immediate and more uncertain compared to biomass-related carbon pools.

In the previous FREL submission, Nigeria assessed national soil characteristics using available soil datasets, including the Harmonized World Soil Database, which indicated that the country is dominated by mineral soils, primarily low-activity clay (LAC) and high-activity clay (HAC) soils, with wetland mineral soils occurring in coastal areas. Based on this assessment and additional data exploration, the absence of peatlands was confirmed, and emissions from deforestation were considered to occur predominantly on mineral soils.

Given that no new national-scale evidence has emerged to alter these conclusions, and considering the continued limitations in reliable, spatially explicit data on SOC stock changes, soil organic carbon has been omitted from the revised FREL. This decision maintains methodological consistency with the 2019 FREL and is consistent with IPCC Good Practice and UNFCCC guidance, which allow the exclusion of carbon pools where changes are expected to be relatively small or where inclusion would introduce disproportionate uncertainty.

3.4. Gases included

Among the three greenhouse gases associated with land use change emissions, namely carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), CO_2 is the main gas emitted in the forest sector. However, significant non-CO_2 gases (CH_4 and N_2O) can also be emitted when land use change is because of fire incidences. In the current FREL submission, CO_2 emissions are estimated for deforestation and forest degradation, while CH_4 and N_2O emissions (expressed in CO_2e) are estimated for fires occurring on Forest Land that result in forest degradation. This approach reflects the availability of newly collected data on the drivers of forest degradation and represents an improvement over the previous FREL submission, in which only CO_2 emissions were accounted for.

3.5 Comparison of Previous and Revised Forest Reference Emission Levels

Table 1 summarises the key differences between Nigeria's previous FREL (2006-2016) and the revised FREL (2017-2021). The revised submission reflects a stepwise methodological improvement, notably through the inclusion of forest degradation as an additional REDD+ activity, expanded carbon pool coverage, and strengthened sampling and QA/QC procedures.

Table 1: Different elements of previous and current FREL

Element	***Previous FREL***	***Current FREL***
Reference Period	2006 - 2016	2017 - 2021
Scale	National	National
REDD+ activities	Deforestation	Deforestation, Degradation
Carbon Pools	Aboveground biomass, below ground biomass and deadwood	Aboveground biomass, below ground biomass, litter and deadwood
Gases	CO_2	CO_2, CH_4, N_2O
Methodology	Stratified Sampling using global product	Systematic Sampling
Sample size	1,215	7,419
QAQC	Multi-interpreter visual interpretation with majority agreement	Convergence of evidence applying algorithms and multi-interpreter agreement
Half-width confidence Interval (%) around deforestation area	46	17

Improvements in the sampling design and quality control framework have resulted in a substantial increase in sample size and a corresponding reduction in uncertainty associated with deforestation area estimates. It is also acknowledged that the multi-interpreter visual interpretation approach with majority agreement applied in the 2019 FREL may have contributed to conservative estimates of deforestation area. While this approach was adopted to enhance accuracy, it may have led to an underestimation of the deforestation area as the average deforestation area from the individual assessments was higher than the deforestation area obtained through majority agreement. Consequently, differences observed between the two submissions may reflect methodological refinements and improved detection rather than (solely) changes in underlying deforestation dynamics.

These enhancements improve the accuracy, transparency, and completeness of the revised FREL.

4. Activity Data

Activity data refers to the extent of human activities, and in this submission consists of forest area changes resulting in emission or removals of GHG, including deforestation, forest degradation, and the enhancement of forest carbon stocks. For this submission, Nigeria employed a sample-based area estimation approach. The methodological framework of this approach is described in this section, subdivided into four main elements:

- Sampling Design
- Response Design
- Data Collection
- Data Analysis

4.1. Sampling Design

A systematic sampling design was selected to generate the activity data for Nigeria's updated Forest Reference Emission Level (FREL) submission. This design ensures that area estimates derived from the interpreted sample data can be considered unbiased (Cochran, 1977; FAO, 2021). This approach is fully consistent with the methodological recommendations of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Volume 4, Chapter 3) and the 2019 Refinement, which emphasize the importance of probabilistic sampling designs for producing reliable and transparent area estimates of land use categories and their transitions.

The sampling grid consists of 7,419 sample units at an effective spacing of 11.2 km × 11.2 km equally distributed across Nigeria. This sampling density is deemed sufficient to represent all land use and land use change categories without introducing under sampling bias, therefore ensuring robust area estimation at national scale. The sampling framework was further informed by operational feasibility within the Nigerian context, with consideration of available resources and realistic timelines for data collection and interpretation. The sampling grid was produced using the Collect Earth Grid Generator (CEGG) with the geographic coordinate reference system EPSG:4326. Figure 1 shows the spatial distribution of

7,419 systematically distributed sample units across Nigeria at an effective spacing of 11.2 km × 11.2 km.

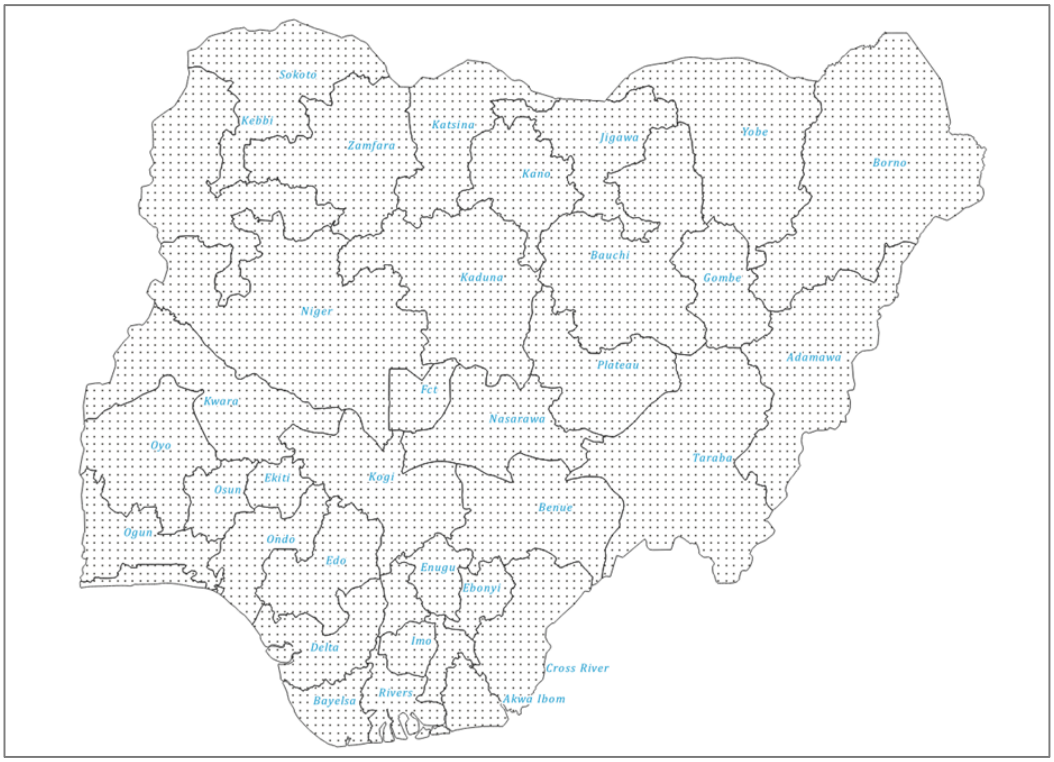

Figure 1: Spatial distribution of the systematic grid

4.2. Response Design

The response design establishes the procedures and protocols used to assign land use and land cover (LULC) classes to each sample unit, ensuring that data collection is accurate, consistent, and efficient for national reporting and REDD+ purposes. The response design applied in this assessment was developed by FAO's Forest Monitoring and Data Platform team and is referred to as a Multipurpose Survey Design (MP-SD). This design has been specifically structured to meet the requirements of multiple reporting modalities and carbon accounting standards, including UNFCCC, the Green Climate Fund (GCF) scorecard, and ART TREES, thereby enabling the generation of harmonized, multipurpose activity data.

This multi-purpose survey design enables Nigeria to produce consistent datasets for both national GHG inventory reporting and international REDD+ submissions without requiring separate interpretation efforts. It also allows for integration of future land monitoring efforts, such as forest degradation assessment, restoration tracking, and land use planning, under a single harmonized data framework, thereby supporting Nigeria's long term MRV system.

The primary objective of the survey is to produce activity data that are fully compliant with the IPCC 2006 Guidelines, the 2019 Refinement, and FAO Good Practice Guidelines (SBAE-2024), ensuring transparency, reproducibility, and reliability of national forest monitoring results.

The response design is structured around five interrelated components:

- Classification scheme
- Land use Land cover classes definitions
- Decision Tree
- Labelling Protocol
- Data Sources
- Post Processing

4.2.1. Classification scheme

The classification scheme follows the IPCC classes and sub-classes used in Nigeria's national monitoring system. Table 2 presents the classes applied in the current assessment, with detailed descriptions provided in Appendix 1.

Table 2: Classification scheme used in the survey

Sr. No.	*IPCC Classes*	*Sub- Classes*
1	Forest	Dense Forest
		Sparse Forest
		Mangrove
		Fresh Water swamp
		Forest Plantation
2	Cropland	Permanent Cropland
		Arable Cropland
		Fallow Land
		Agroforestry
3	Grassland	Natural Grassland
		Savanna Wooded land
4	Settlement	Settlement
5	Wetland	Waterbody
		Wetland
6	Other land	Bare land

4.2.2. Land use Land cover classes definitions

This section provides definitions of land use/land cover (LULC) classes and activity data classes. Additional details, including explanatory variables and examples, are presented in Appendix 1.

1. **Stable Forest:** Forest Land Remaining Forest land during monitoring period.
2. **Stable Non-Forest:** Non-Forest Land remaining non-Forest land during monitoring period.
3. **Deforestation:** A change from forest to non-forest LULC refers to a permanent conversion where the land no longer functions as a forest.
4. **Forest Degradation:** Refers to changes within forested areas where the land continues to meet the definition of forest, and no change in land use occurs. These changes often involve a decline in forest quality, such as reduced canopy density, biomass, without crossing the threshold into non-forest status.
5. **Regrowth:** Enhancement of forest carbon stocks includes both enrichment in carbon stocks in forest remaining forest, as well as enrichment in carbon stocks through afforestation/reforestation and natural regeneration of forest.
6. **Forest:** In accordance with the national forest definition presented in section 2.4, forest in the FREL analysis was further stratified into forest subcategories to support AD interpretation and emission estimation. These subcategories do not include alternative definitions for forest, but are groups applied within the national forest definition. The following subcategories were used:
    a. **Forest Dense**: Forest, dense refers to areas of natural forest cover with a high canopy density, specifically where the canopy cover is 70% or greater.
    b. **Forest Sparse**: Forest, sparse, refers to forested areas where the canopy cover ranges between 15% and less than 70%.
    c. Forest Plantation: Forest plantation is defined as any homogeneous tree planting or forest regeneration with the purpose of timber, fibre, fruit or tree sap harvest for a commercial local, national or international market.
    d. Mangrove/Freshwater Swamp Forest: refers to a mosaic of marine and freshwater-associated vegetation types typically found along coastlines, creeks, estuaries, riverbanks, and marshy areas. These forests may occur as pure stands or in mixtures with species such as Nypa palm, Raphia,

hydrophytes and other wetland vegetation. Canopy closure ranges from 15% to 100%.

7. **Non-Forest**

7.1. Cropland

a. **Arable Cropland:** refers to land that is regularly cultivated and used to produce annual or short-cycle crops, such as cereals, legumes, vegetables, and tubers.

b. **Fallow land:** refers to agricultural land that is temporarily left uncultivated to restore soil fertility and allow ecological recovery. It may be covered with natural vegetation and is typically intended for future cultivation.

c. **Permanent Crops:** Primarily consists of fruit tree crops such as cocoa, rubber, oil palm, tea, gum Arabic, orchards, coffee, and cashew. The land is dominated by crops for commercial or subsistence purposes, either as monoculture plantations or integrated with other crops.

d. **Agroforestry:** is the cultivation of agricultural crops both annual and permanent with the integration of forest trees. Presence of trees either scattered or clustered within a cropland.

7.2. Grassland

a. **Natural Grassland:** refers to open areas dominated by native grasses, herbaceous plants, and meadows, with less than 15% tree cover and dominated by shrubs.

b. **Savanna Woodland:** refers to a savanna landscape characterized by a mix of grassland and scattered trees or shrubs, where the tree canopy cover is less than 15%, mostly dominated by drought-resistant vegetation and dominated by shrubs and herbaceous vegetation.

7.3. Wetlands

a. **Wetland:** Ramsar Convention (international standard): Wetlands are areas of marsh, fen, or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish, or salt, including areas of marine water the depth of which at low tide does not exceed six meters.

b. **Water Bodies:** Water bodies are natural or artificial accumulations of water, either static or flowing, that occupy a significant area of the land surface. This includes rivers, lakes, reservoirs, and coastal waters, water Dams, pounds.

7.4. Settlements: This category includes all developed land, including transportation infrastructure and human settlements of any size, unless they are already included under other categories.

7.5. Other land: This category includes bare soil, rock, ice, and all unmanaged land areas that do not fall into any of the other five categories. It allows the total of identified land areas to match the national area, where data are available.

4.2.3. Decision Tree

The interpretation starts with the identification of the land use class in 2024. Subsequently, the history of that sample is assessed retrospectively. For plots where no changes occurred during the data collection period, only the current land use class (2024) was recorded.

Whenever a LULC change was observed during the data collection period, the LULC class corresponding to the change year was recorded. Additionally, information on the year of change was collected. In case of LULC change event, the drivers of change are extracted based on the observed LULC transitions. This approach allowed to record multiple changes over the study period, up to a maximum of four transitions per sample plot.

In instances where the 2024 LULC class was Forest, the sample was further inspected for indications of disturbance (e.g., fire, logging) or enhancement (e.g., increases in carbon stock). When such events were identified, additional information was collected:

- For **degradation/disturbance events**, the disturbance driver and the year of occurrence were recorded. The list of drivers captured includes;
  - Fire
  - Logging
  - Wood fuel and Charcoal
  - Flooding,
  - Soil erosion

    - Others
- For **enhancement events**, information related to drivers of carbon stock increases, along with the year of enhancement, was captured.

The response design adopted a Land Use and Land Cover (LULC) approach rather than a direct change class assessment. By requiring interpreters to assign independent LULC classes to each sample guided by a structured survey and decision tree. The protocol effectively reduces the cognitive load associated with predefining complex change trajectories. This shift away from the traditional "change class" concept addresses a persistent challenge in land monitoring: the subjectivity and ambiguity of defining multiple transitions.

Focusing on independent, time-specific labelling ensures greater data consistency across interpreters and avoids the creation of disparate statistics often seen in direct change class reporting. Furthermore, this approach offers superior flexibility for post-classification analysis, allowing for the seamless aggregation of data into REDD+ activity categories and ensuring alignment with IPCC guidelines. The result is a more robust framework for analyzing land-use transitions and drivers, ultimately providing more accurate carbon stock estimations for UNFCCC reporting.

Figure 2 presents the layout of the survey design used. (1) The first card appears when the interpreter selects a sample and is used to record the LULC class for 2024. (2) The second window appears only when a change event, specifically an LULC change, needs to be recorded. (3) The third window is designed to capture any uncertainty the interpreter may have during interpretation, allowing the sample to be flagged for reinterpretation.

Figure 3 illustrates the survey elements designed to capture degradation and enhancement within the current data collection framework. (4) refers specifically to the degradation drives used when recording forest degradation events. (5) indicates that if the interpreter selects “None” from the list of “Any Disturbance”, the system automatically prompts the collection of regrowth information, using the driver list shown in the screenshot above.

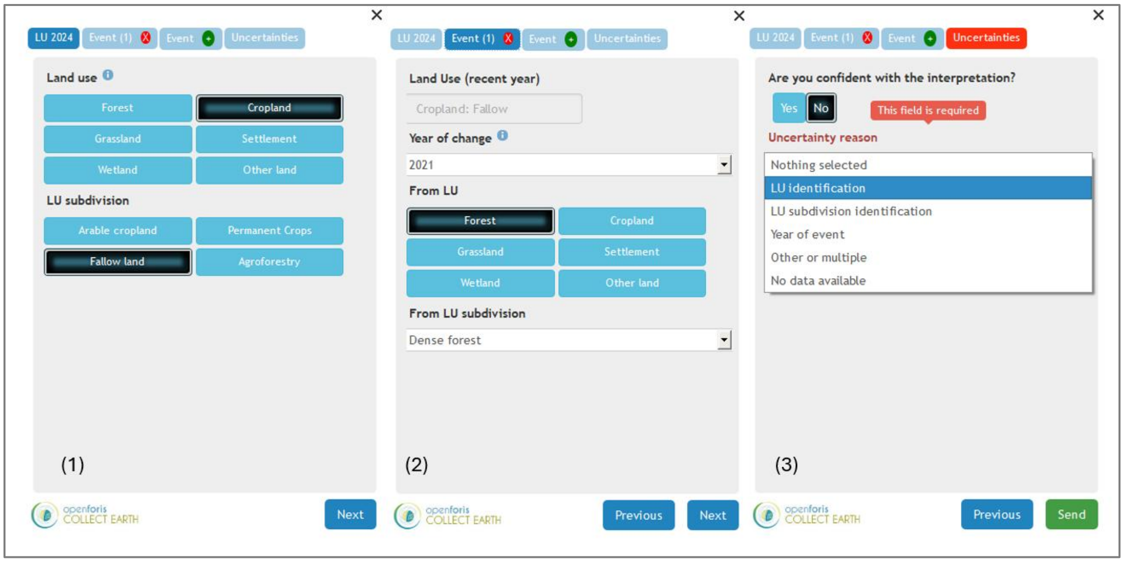

Figure 2: Layout of the survey design

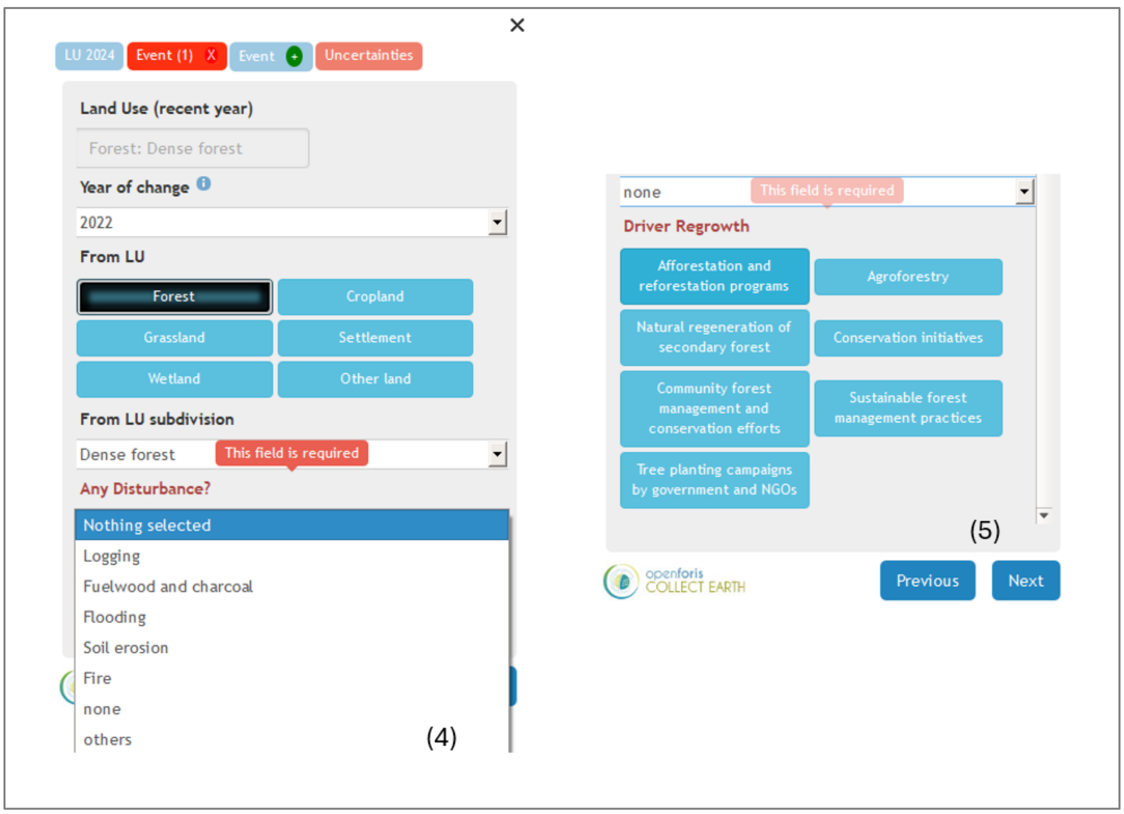

Figure 3: Survey elements for degradation and enhancement

4.2.4. Labelling Protocol

In visual interpretation of satellite imagery for LULC, the labelling protocol defines the rules and criteria used to assign LULC classes to individual sample plots. It starts with mental delineation of land use classes over the sample plot, taking into account the definitions. The land use overlapping the 0.5 ha sampling unit determines the label of the sample plot for a specific year. In the case of multiple land use classes overlapping the sampling unit, a majority rule is applied.

In this study, the dominance (or majority) rule with context protocol was applied, where the predominant LULC type within a plot was assigned as the main class, while also considering contextual information from surrounding areas to improve accuracy. The spatial assessment unit in this case was 0.5 ha square. When the spatial unit assessment intersected multiple LULC types, interpreters assessed the surrounding landscape context and assigned the dominant class within the spatial assessment unit.

Figure 4 represents a systematically selected grid cell. The yellow bounding box overlaid on the satellite image indicates the spatial unit, which covers an area of 0.5 hectares. The central point within the box marks the central location of the sample. (a) The satellite image shows a dense forest cover, in 2012 while (b) the 2021 image show a change event. Although part of the sample unit still contains vegetation, based on the majority rule, this unit is classified as a change event occurring in 2021. The interpreter will revise the history of the plot, utilizing additional imagery from sources such as Sentinel-2 and Landsat. Since the temporal consistency of Google Earth Pro imagery varies, these auxiliary datasets were essential for accurately determining the exact year of change. (d) illustrates the Continuous Change Detection and Classification (CCDC) time series, which further confirms the current land use/land cover (LULC) transition observed in the sample plot.

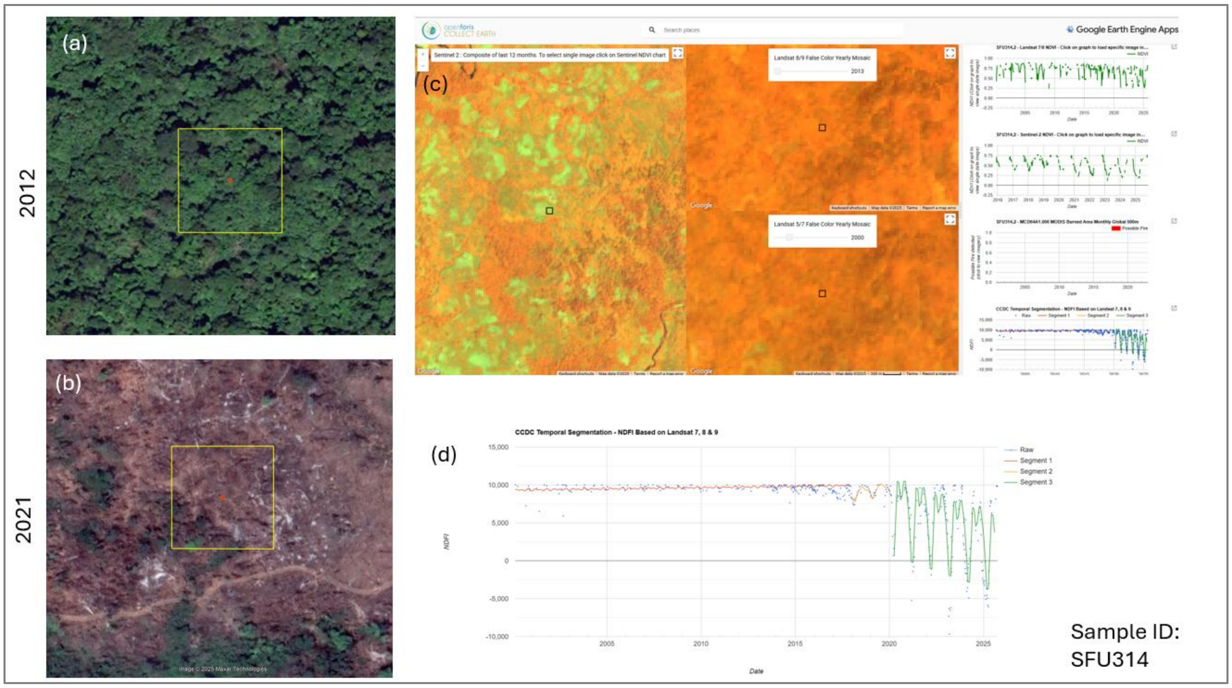

Figure 4: Example of sample interpretation

For each sample unit, the LULC class was recorded for the year 2024 and for all identified change years (up to four per plot). Because land use changes and disturbance events are rare phenomena, this event-based system records changes only when a transition is detected. In the absence of a recorded event, the sample plot is presumed stable, inheriting its 2024 LULC label for all preceding years with no detected change. This approach enhances interpretive efficiency and data consistency, centring analytical effort on transitions, which typically constitute a small fraction of the landscape.

4.2.5. Data Sources

Data were collected using the Collect Earth (CE) tool, part of the Open Foris[1] set of tools, which provides efficient access to multi-source satellite imagery for visual interpretation. For LULC assessment, interpreters accessed very high-resolution imagery from Google Earth Pro (spatial resolution < 1 m), Planet NICFI annual composites (3-5 m), Sentinel-2 imagery (10 m), and Landsat imagery (30 m), made available through Google Earth Engine (GEE).

[1] https://openforis.org/solutions/collect-earth/

4.2.6. Post Processing

In accordance with the IPCC land use classification framework, each observation was assigned to either Forest Land or Non-Forest Land, thereby enabling the derivation of land use transition classes through logical comparison across observation years. Forest Land corresponds to the IPCC Forest Land category, while the remaining IPCC land use categories; Cropland, Grassland, Wetlands, Settlements, and Other Land correspond to Non-Forest Land. The final activity change classes were then determined through a rule-based process applied sequentially as follows:

- **Deforestation** assigned when the LULC in 2024 was Non-Forest (NF) and previous LULC was Forest (F).
- **Regrowth (Forest Gain)** assigned when the LULC in 2024 was Forest (F) and the previous LULC was Non-Forest (NF).
- **Disturbance** assigned when LULC remain Forest (F → F) in both recent and previous year, but changes in forest services observed and disturbance driver (e.g. fire, logging, etc) was recorded by the interpreter.
- **Stable Forest** is when the LULC 2024 was Forest (F) and no change event was recorded throughout the observation period.
- **Stable Non-Forest** was assigned when the LULC 2024 was Non-Forest (NF) and no change event was recorded throughout the observation period.
- **Non-Forest Change (NF-Change)** are changes observed among non-forest IPCC classes (e.g., Cropland ↔ Grassland ↔ Settlement) without any transition involving forest land.

4. 3. Data Collection

Prior to data collection, selected staff from relevant Nigerian institutions participated in a virtual training organized by FAO. The training mainly focused on visual interpretation of satellite imagery, familiarizing interpreters with the response design, survey design, and introducing key features and workflows within Collect Earth software.

Data collection was implemented using the Collect Earth tool and applied the satellite imagery sources described in Section 4.2.5. Interpreters assessed land use and land use change in accordance with the nationally agreed response design, recording attributes required for the calculation of activity data for the FREL reference period.

The data collection process was coordinated by the National REDD+ Secretariat, with technical support provided by Landell Mills under the Climate Action Africa programme funded by Alinea International, and additional technical backstopping from FAO. Interpretation decisions were made independently by trained national interpreters following the agreed protocols.

Sample units were randomly selected and distributed as evenly as possible among 17 interpreters (see Appendix 4) to reduce potential bias in sample allocation. In addition to the response design protocols, additional quality control (QC) and quality assurance (QA) measures were implemented to ensure data accuracy, consistency, and reliability. The following section provides a detailed description of these procedures.

4.3.1. Quality Assurance and Quality Control (QA/QC)

Visual interpretation of satellite imagery remains a cornerstone for collecting reference data in land cover and land-use assessments. This process involves the manual classification of sample units to generate robust area estimates. However, visual interpretation is inherently susceptible to errors arising from limitations in spatial resolution, seasonal phenology, observer bias, and spectral similarity between distinct land cover classes (Pengra et al., 2020; Powell et al., 2004; Radoux et al., 2019; Stehman et al., 2022).

These limitations can lead to omission errors (missed transitions) or commission errors (falsely identified changes). Given that precise detection of forest changes and land-use transitions is critical for IPCC-compliant reporting, several Quality Assurance and Quality Control (QA/QC) protocols were implemented. These include cross-validation, iterative reinterpretation, and the integration of independent data sources to improve reliability and internal consistency. Following the framework established by Radoux et al. (2019), potential interpretation errors are categorized into three primary groups thus:

- **Vigilance Errors:** which arise from performing monotonous tasks over extended periods or from an interpreter's subjective bias. To mitigate these risks, several quality control measures were implemented.
    - Structured breaks were mandated during interpretation sessions to maintain focus and reduce fatigue. In addition, to avoid reliance on a single operator’s perspective, interpretation was conducted by multiple trained interpreters, ensuring workload balance and continuity throughout the data collection process.
- **Systematic Errors:** These refer to incorrect labelling, often resulting from a lack of interpreter expertise or unfamiliarity with the imagery.
    - To address systematic errors, a multi-interpretation exercise was conducted both before and after the reference data collection. This process served two primary functions: first, it identified **confusion classes**, specific LULC categories that interpreters found difficult to distinguish; and second, it measured **inter-rater agreement**. While the initial assessment revealed low levels of agreement, the subsequent training and data collection phases led to a significant alignment in interpretation. This demonstrates a great improvement in data quality and interpreter proficiency, as illustrated in the comparative analysis described in the “QAQC results” section below.
- **Estimation Errors:** These involve discrepancies in class proportions within sampling units, often caused by landscape complexity or the classification scheme itself.
    - Estimation errors were minimized through a rigorous response design and the application of a comprehensive **interpretation key**. To further refine the dataset post-collection, a targeted quality control phase was implemented, where sample subsets identified with potential omission or commission errors were **reinterpreted**. Additionally, samples flagged by interpreters as **uncertain** underwent a **group review process**. In these sessions, interpreters collaborated to reach a **consensus label**, ensuring that the most challenging cases were resolved through collective expertise rather than individual guesswork.

In the current assessment, two specific strategies were implemented to **mitigate systematic** and **estimation errors**. These approaches ensure that the final area estimates are both accurate (unbiased) and precise (low variance). The following sections provide a detailed technical breakdown of these measures.

4.3.1 Multi-interpretation approach

Prior to the main data collection, a subset of 200 samples was independently interpreted by all interpreters (multi-interpretation over samples). Multi-interpretations are considered highly useful to evaluate the inter-rater agreement whereby the same set of samples were evaluated multiple times.

This preliminary exercise was conducted prior to the actual reference data collection. The primary objective was to assess and strengthen the capacity of interpreters in applying the LULC classification system and performing consistent visual interpretation.

This process facilitated an evaluation of the national capacity in visual interpretation, identified potential confusion areas, and highlighted areas where interpretation guidelines could be refined. By addressing these issues early, the team ensured greater consistency and accuracy in the subsequent reference data collection.

4.3.1.1. Sampling Framework for Evaluating Interpretation Consistency

Samples were selected from the systematic grid, stratified using the Tropical Moist Forest (TMF) data, to ensure representation of rare classes. The TMF data for the latest available year (2024) was regrouped into five categories: Deforestation, Forest Degradation, Regrowth, Undisturbed Forest, and Others. The systematic grid was overlaid onto stratification layer, and an equal number of samples (40 samples per class) from each stratum was selected randomly. The reclassification and sample selection procedures were implemented in Google Earth Engine (GEE) using a dedicated script.

Following sample selection, the same set of samples was provided to all interpreters for independent data collection to ensure comparability and to identify areas requiring further guidance and harmonization.

4.3.2 Correction of potential omission and commission errors in activity data

This setup was performed after the first round of reference data collection was completed. First round interpretations were combined with additional information, including global datasets and change probability information derived from time-series analysis, to identify potential omission or commission errors. These samples were then reinterpreted, ensuring that detected changes accurately reflected real world conditions and improving the overall reliability of the dataset.

The QA/QC method employs a cross-comparison of global forest cover change datasets (Convergence of Evidence) and classification probabilities of time-series change analysis (eSBAE) against the first-round interpretations. Samples exhibiting inconsistencies are prioritized for inconsistency checks. The approach assumes that convergence among multiple independent datasets increases the likelihood of identifying true land use changes and reduces systematic bias in the final activity data.

Given that the reference period of interest was 2017 - 2021, all samples were first categorized into two broad groups based on visual interpretation:

- **Forest Change samples:** Deforestation, Degradation and Regrowth
- **No change samples:** Stable Forest, Stable Non-Forest and NF transitions

4.3.2.1 Convergence of Evidence

Using this approach, information over sample grid was extracted from global products, mainly RADD alerts, Global Forest Change (GFC) and Tropical Moist Forest (TMF) products using the Whisp application[2], for proposed reference period. Two types of potential misclassifications were targeted here:

- **Potential Omission Errors:** Samples interpreted as no change but identified as change by at least one global product (e.g., GFC, Tropical Moist Forest TMF and RADD alerts) were flagged as potential omissions. These represent possible missed changes in the current interpretation and might lead to underestimation of change.

[2] https://openforis.org/solutions/whisp/

- **Potential Commission Errors:** Samples initially labelled as change but identified as no change in global products were flagged as potential commissions. These checks were designed to minimize overestimation of change.

4.3.2.2 Time-Series analysis Using eSBAE

In addition to cross checking global products, an independent time series verification was also performed using multiple remote sensing datasets and change detection algorithms as predictor variables, along with visual interpretation as the response variable, to train a model that identifies discrepancies in the interpreted data (method referred to as eSBAE). Landsat time series data was processed for the period 2013 - 2025 to generate change probability layers.

A subset of 30 percent randomly selected interpreted samples was used to train a Random Forest classifier, applied over the systematic sampling grid (7,419) to derive Forest & Non-Forest (FNF) probability for the year 2017 and 2021. The difference between these two probability layers was computed to quantify the likelihood of change at each sampling location.

- Samples exhibiting a **change probability exceeding 70%** yet classified as "no change" during interpretation were identified as potential omission errors.
- Conversely, samples interpreted as "change" but demonstrating a **change probability below 30%** were flagged as potential commission errors, indicating possible overestimation of change events.

4.3.3. Sample Consolidation and Reinterpretation

Because certain samples were identified by multiple verification sources (e.g., both global datasets and eSBAE), duplicate entries were removed, and all flagged samples were consolidated into a single dataset for re-interpretation.

In total, 1,536 samples (approximately 20% of the full sample set) were re-interpreted. These samples were reviewed using the same methodology outlined above and used for the first round of interpretation. In addition to samples identified for potential omission and commission errors, all samples classified as low confidence, as well as those exhibiting sub class transitions e.g., shifts from dense to sparse forest were also included in the reinterpretation.

A group review session was subsequently conducted for samples flagged with uncertainty, enabling consensus-based validation among interpreters. This iterative process aligns with IPCC good practice guidance, ensuring that neither underestimation nor overestimation of forest changes occurs in the final activity dataset.

Figure 5 illustrates the spatial distribution of samples selected for QA/QC and reinterpretation using two approaches: the convergence of evidence (shown in orange) and the eSBAE approach (shown in red). In addition, all samples exhibit a certain level of uncertainty along with those belonging to sub-classes changes (shown in blue). Since the survey design restricted sub-class level change detection for degradation and regrowth events, these cases were not captured during the initial screening due to technical issues in the query setup. Consequently, during the second QA/QC round, all samples sharing the same main LULC class but differing in sub-class labels were systematically reviewed and re-evaluated.

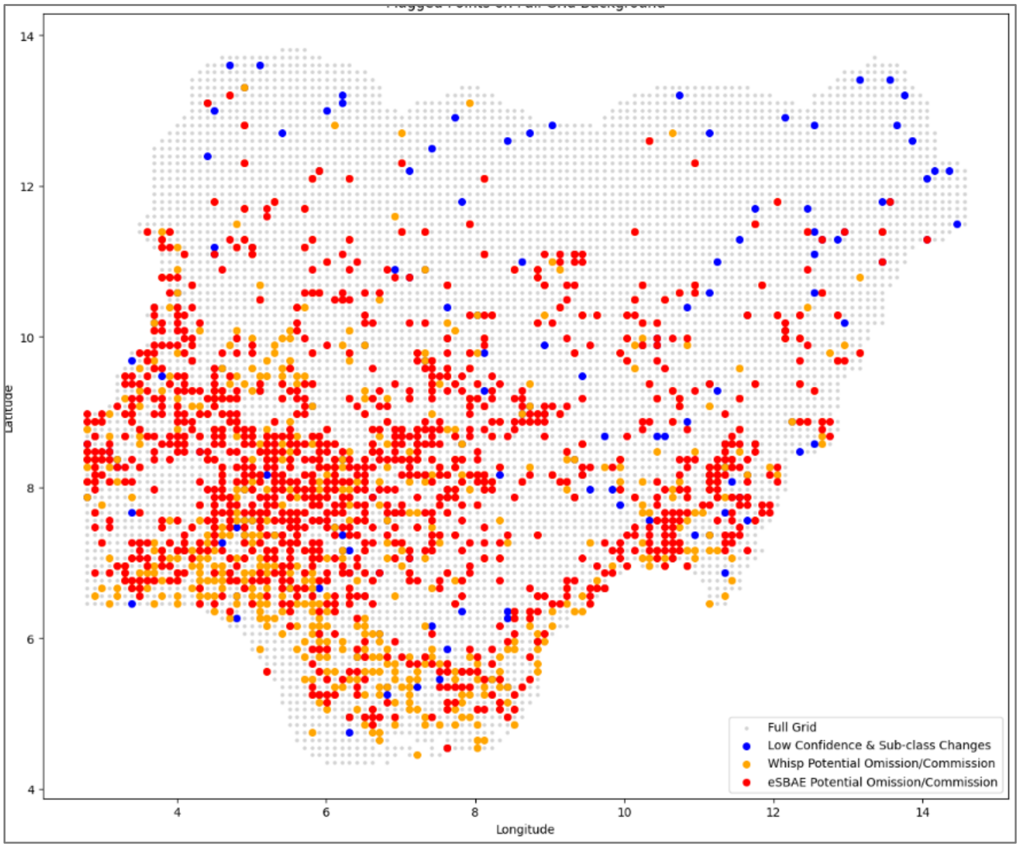

Figure 5: Spatial distribution of QA/QC samples

4.3.4. Final Data Integration

After completing all QA/QC procedures, the revised samples were merged with the original dataset. In cases where discrepancies persisted, the latest interpretation was assumed to represent the most accurate assessment. The integrated, quality-controlled dataset was then used as the final input for area estimation and activity data analysis.

This multi-tiered QA/QC framework combining independent datasets, probabilistic time series verification, and expert reinterpretation ensures that Nigeria's FREL activity data are transparent, verifiable, and consistent with the principles of methodological rigor required under the UNFCCC Measurement, Reporting and Verification (MRV) framework.

4.4. Data Analysis

For the current analysis, the systematic grid was post-stratified using the ecological zones shapefile to calculate activity data, in order to maintain consistency with the previous FREL. These ecological zones serve as permanent strata for Nigeria.

4.4.1. Area Estimates and Uncertainty calculation

Area estimates were derived by multiplying the total number of samples in a given class of relevant stratum by the corresponding stratum expansion factor to obtain the total area of each class within that stratum (Equation 1). As ecological zones were used as strata, standard errors were also calculated using the appropriate statistical formulation for a stratified sampling estimator (Equation 2). All area estimates and their associated uncertainties were calculated using Excel.

$$\boldsymbol{Aij = nij * wi} \qquad \textbf{Equation 1}$$

Where:

A_{ij} = *Area of class j in stratum i.*

n_{ij} = *Total number of samples of class j in stratum i.*

w_i = *Expansion factor of stratum i.*

$$\boldsymbol{SE = \sqrt{pij\frac{1-pij}{ni-1}} * Ai} \qquad \textbf{Equation 2}$$

Where:

SE = *Standard Error calculated for each class j in stratum i*

p_{ij} = *Proportion of class j in stratum i, calculated as* $p_{ij} = \frac{n_{ij}}{n_i}$

n_i =*Total number of samples in stratum i.*

A_i = *Total area of stratum i.*

4.4.2 Spatial Distribution and Drivers of Deforestation across Ecological Zones

The analysis of activity data for the reference period indicates clear spatial and temporal patterns of deforestation across Nigeria's ecological zones. Deforestation is highest in the Guinea Savanna, followed by the Derived Savanna and Lowland Rainforest zones (Figure 9). These zones account for the largest share of national forest loss, reflecting intense land-use pressures associated with agricultural expansion and settlement growth.

In contrast, deforestation levels are comparatively lower in the Mangrove and Freshwater Swamp, Montane Forest, and Sudan and Sahel Savanna zones.

Analysis of deforestation drivers (Figure 10) indicates that conversion to arable cropland is the dominant driver of deforestation nationally, particularly within the Guinea and Derived Savanna zones. Transitions from agroforestry systems and fallow land to cultivated cropland also contribute substantially to forest loss, highlighting the role of smallholder agricultural expansion. Additional drivers include settlement expansion and, to a lesser extent, conversion to permanent crops and savanna woodland, with these drivers exhibiting localized importance across different ecological zones.

Overall, the results demonstrate that deforestation in Nigeria is primarily driven by land-use transitions associated with agricultural expansion, particularly in savanna ecosystems, while forest losses in high-forest zones are more spatially limited but environmentally significant. These findings underscore the importance of targeted, zone-specific policy interventions, especially those addressing agricultural expansion and land-use planning, to effectively reduce deforestation-related emissions under REDD+.

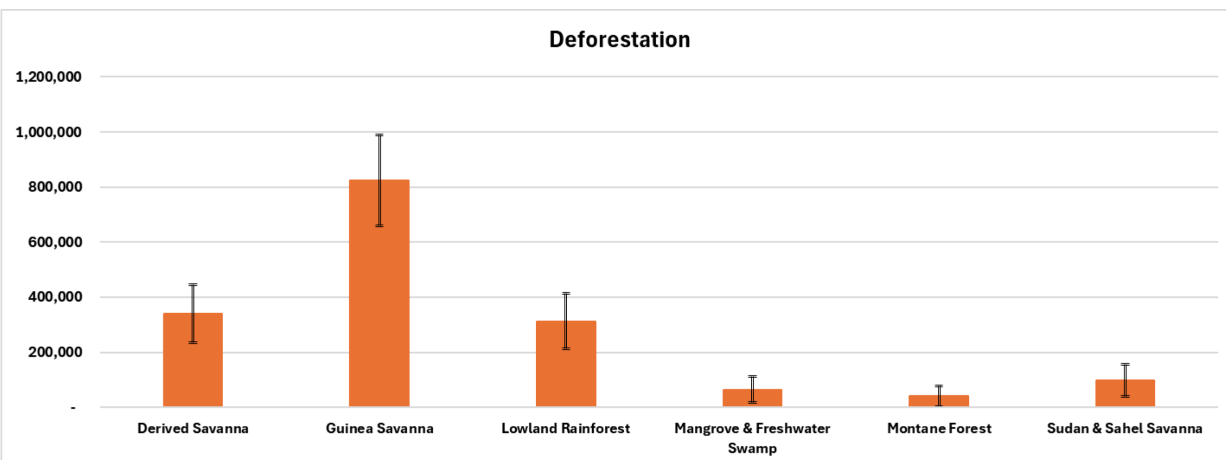

Figure 6: Deforestation by ecological Zones along with 90% CI

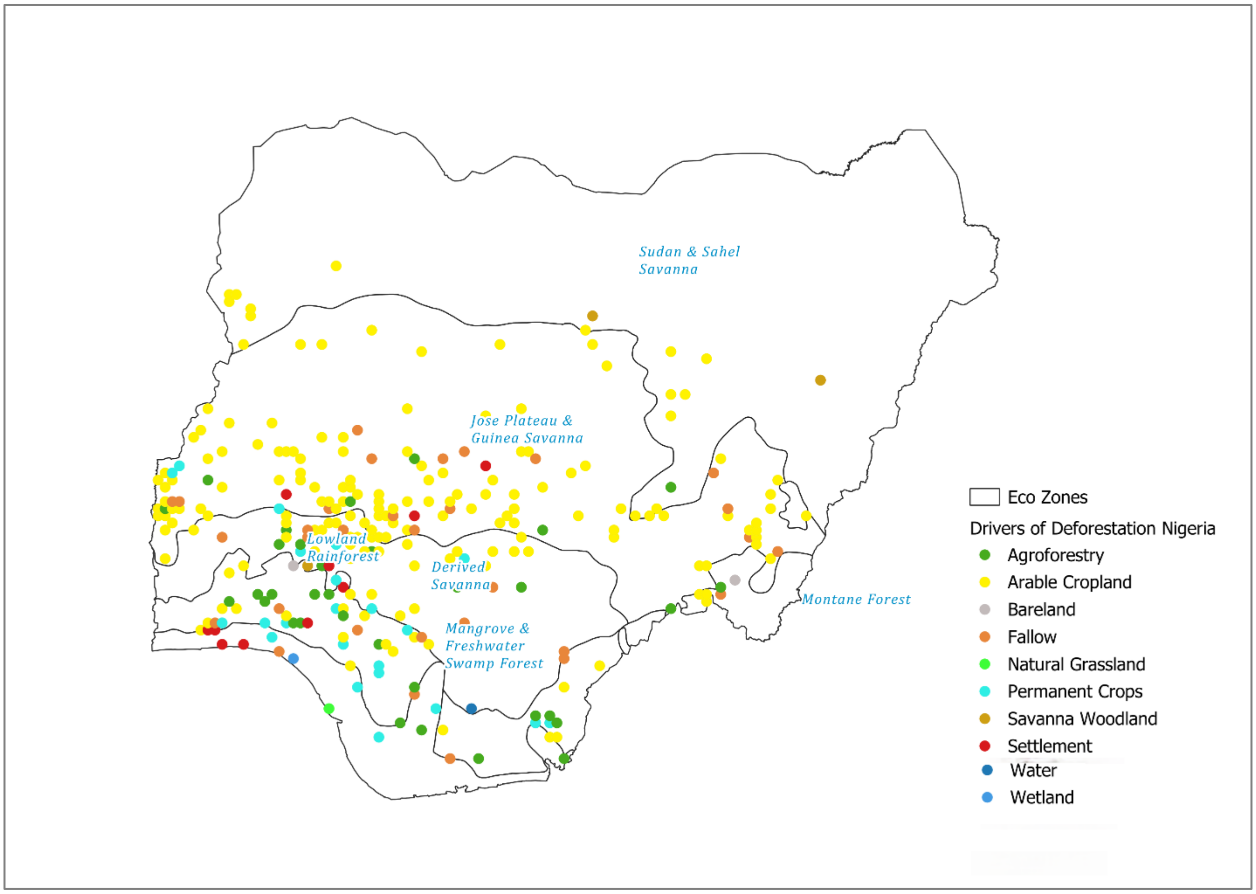

Figure 7: Spatial distribution of drivers of Deforestation in Nigeria by ecological zones

4.4.3 Spatial Extent of LULC Transitions (2017–2021)

Tables 3 present the distribution of samples by ecological zone in Nigeria used for activity data (AD). The Sudan & Sahel Savanna and the Guinea Savanna are the two largest ecological zones in the country, they contain the highest number of samples, reflecting their larger proportional area. In contrast, the Montane Forest area represents the smallest stratum and contains 132 samples only.

Table 4 presents the estimated area of LULC transitions across the ecological zones for the reference period 2017 - 2021. The total area of deforestation approximately 1.68 million ha with the highest contribution from the guinea savanna. The annual deforestation rate for the reference period is 335,811 ha/year (2017 – 2021). The annual area of forest degradation is 35,340 ha/year which was dominant in the guinea savanna. The total stable forest for the period is about 12.13 million ha, and the stable non-forest covers about 75.60 million ha.

Table 3: Samples distribution by classes and Ecological Zones

Class	Derived Savanna	Guinea Savanna	Lowland Rainforest	Mangrove & Freshwater Swamp	Montane Forest	Sudan & Sahel Savanna	Total
Deforestation	27	66	25	5	3	8	134
Degradation	1	8		3	1	1	14
NF Changes	17	74	12	5	1	99	208
Regrowth	4	3				9	16
Stable Forest	125	305	148	171	70	144	963
Stable NF	679	1844	412	145	57	2947	6084
Total	853	2300	597	329	132	3208	7419

Table 4: Area (ha) estimates by Ecological Zones (permanent strata)

Class	Derived Savanna	Guinea Savanna	Lowland Rainforest	Mangrove & Freshwater Swamp	Montane Forest	Sudan & Sahel Savanna	Total
Deforestation	339,504	824,392	312,505	64,337	39,887	98,432	1,679,056
Degradation	12,574	99,926	-	38,602	13,296	12,304	176,702
NF Changes	213,761	924,319	150,002	64,337	13,296	1,218,094	2,583,809
Regrowth	50,297	37,472	-	-	-	110,736	198,505
Stable Forest	1,571,776	3,809,691	1,850,029	2,200,324	930,688	1,771,774	12,134,281
Stable NF	8,537,886	23,033,019	5,150,080	1,865,771	757,846	36,259,843	75,604,446
Total	10,725,797	28,728,820	7,462,616	4,233,371	1,755,012	39,471,183	92,376,800

4.4.4 Uncertainty Assessment of LULC Transition Area Estimates

Table 5 presents the relative uncertainty (confidence interval, %) of area estimates for each activity class across Nigeria's ecological zones. Uncertainty levels vary substantially by activity and zone, with higher relative uncertainty observed for degradation, regrowth, and non-forest change classes, reflecting their more fragmented spatial patterns and lower sample frequencies. In contrast, stable forest and stable non-forest classes exhibit consistently lower uncertainty, indicating greater classification confidence and spatial coherence. Overall uncertainty is lowest for stable classes and highest for dynamic change processes, underscoring the importance of continued improvements in sampling density and reference data for less frequent forest transitions.

Table 5: Relative uncertainty (confidence interval, %) of area estimates

Class	Derived Savanna	Guinea Savanna	Lowland Rainforest	Mangrove & Freshwater Swamp	Montane Forest	Sudan & Sahel Savanna	Total
Deforestation	37	24	38	87	112	69	17
Degradation	196	69	-	113	196	196	52
NF Changes	47	22	56	87	196	19	13
Regrowth	98	113	-	-	-	65	49
Stable Forest	16	10	14	10	16	16	5
Stable NF	3	2	5	12	20	1	1

4.4.5 QAQC results

4.4.5.1 Multi interpreter analysis

A multi-interpreter analysis was conducted using the Kappa coefficient, a commonly applied metric for assessing inter rater agreement. A dedicated Python script was developed to perform the analysis, generating pairwise agreement statistics for each interpreter across the defined LULC. Unlike raw agreement metrics, the Kappa coefficient accounts for the level of agreement that may occur by chance, providing a more robust assessment of consistency.

Prior to the main reference data collection, the QA/QC subset of 200 samples was interpreted by all interpreters. The initial results indicated relatively low agreement and highlighted several confusion classes. Based on these findings, additional training and clarification sessions were organized to strengthen the team's interpretation capacity.

Following completion of the reference data collection, all interpreters were asked to re-interpret the same set of samples. For this round, only the samples with initial disagreement were reassigned. The subsequent analysis demonstrated a clear improvement in agreement levels, indicating enhanced interpreter performance over time and increased confidence in the consistency of the reference data produced.

Figure 11 presents the Pairwise agreement among interpreters for change classes. Round 1 (a): Results from the initial interpretation of the 200 QA/QC samples, highlighting the level of agreement between each pair of interpreters. This round revealed lower agreement levels. Round2 (b): Results from the re-interpretation of samples with initial disagreement, following targeted training and guidance. Improved pairwise agreement in this round indicates enhanced consistency among interpreters and greater confidence in the reference data.

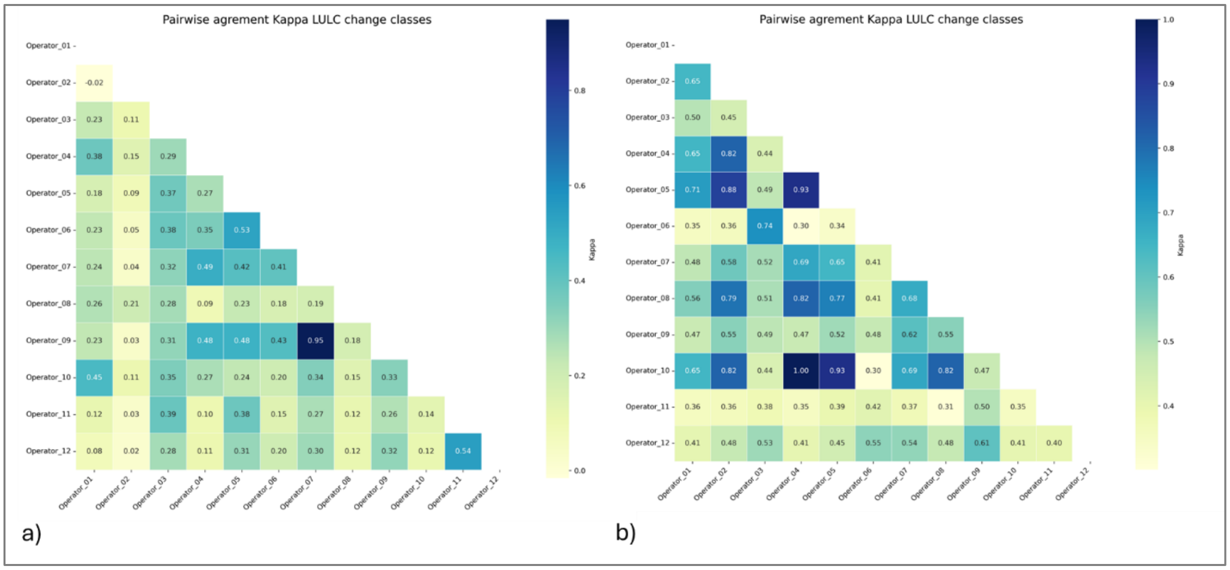

Figure 8: Pairwise agreement among interpreters for change classes

4.4.5.2 Correction of potential omission and commission errors Analysis

Following the reinterpretation of 1,535 samples, the results were re-analysed by categorizing the observations based on identified errors and the approaches applied for sample review. As presented in Table 6, the convergence of evidence was found to be particularly effective in reducing potential underestimation of change (17.7 %), primarily by flagging plots where subtle or overlooked transitions were likely. In contrast, the eSBAE approach was more effective in identifying and correcting potential commission errors (43%).

Table 6: QAQC results using eSBAE and convergence of evidence approaches

Error Type	***Method***	***Total Samples Flagged***	***Corrected***	***Uncorrected***	***% Corrected***
Omission	e-SBAE only	458	50	408	10.9
Omission	Convergence of Evidence only	344	61	283	17.7
Omission	Both	114	31	83	27.2
Commission	e-SBAE only	121	53	68	43.8
Commission	Convergence of Evidence only	88	16	72	18.2
Commission	Both	337	77	260	22.8

A number of samples underwent revised interpretation during the second review, particularly in instances where both approaches independently flagged a plot as exhibiting potential change. This dual flagging mechanism strengthened the reliability of the final data and contributed to an overall improvement in data consistency and accuracy. The application of these complementary QA/QC procedures ensured a more robust identification of LULC dynamics, thereby enhancing the integrity of the activity data used for the UNFCCC reporting process and ensure change is not over or underestimated.

5. Emission Factors Estimation

Emission factors (EFs) used in this revised Forest Reference Emission Level (FREL) are derived from Nigeria's National Forest Inventory (NFI) and associated biomass assessments, following the methodological framework described in Section 6.2 of the 2019 national FREL submitted to the UNFCCC. The full NFI dataset was published in 2020, after the submission of the 2019 FREL, and constitutes the most comprehensive and nationally representative source of forest biomass data currently available (FAO, 2020).

No additional nationally published NFI datasets have become available since that time. Consequently, the same NFI dataset, sampling design, plot measurements, biomass equations, and carbon conversion factors applied in the previous FREL have been retained for this revised FREL. The estimation of emission factors is therefore methodologically consistent with the previous submission, ensuring comparability between FRELs, while allowing the revised FREL to focus on expanded activity coverage and improved activity data.

5.1. NFI Sampling Design

As described in the 2019 national FREL, Nigeria applied a stratified sampling design based on ecological zones to capture spatial variability in forest carbon stocks across the country. Sample clusters were distributed to ensure adequate representation of major forest types, including lowland rainforest, mangrove and freshwater swamp forests, savanna forests, and montane forests.

The sampling framework adopted in the previous FREL remains valid and has therefore been retained for this revised submission. Details of the National Forest Inventory (NFI) sampling framework including cluster distribution across ecological zones, plot configuration, and field measurement protocols are fully documented in Sections 6.2.1–6.2.3 of the 2019 FREL and are not repeated here. The inventory design provides statistically representative coverage of Nigeria's major ecological zones and forest types and continues to constitute the most robust national dataset for forest biomass estimation.

Figure 6 shows the NFI plot design. Cluster design used for the inventory (a), and Spatial Distribution of Sample Clusters visited and measured in different Ecological Zones (b).

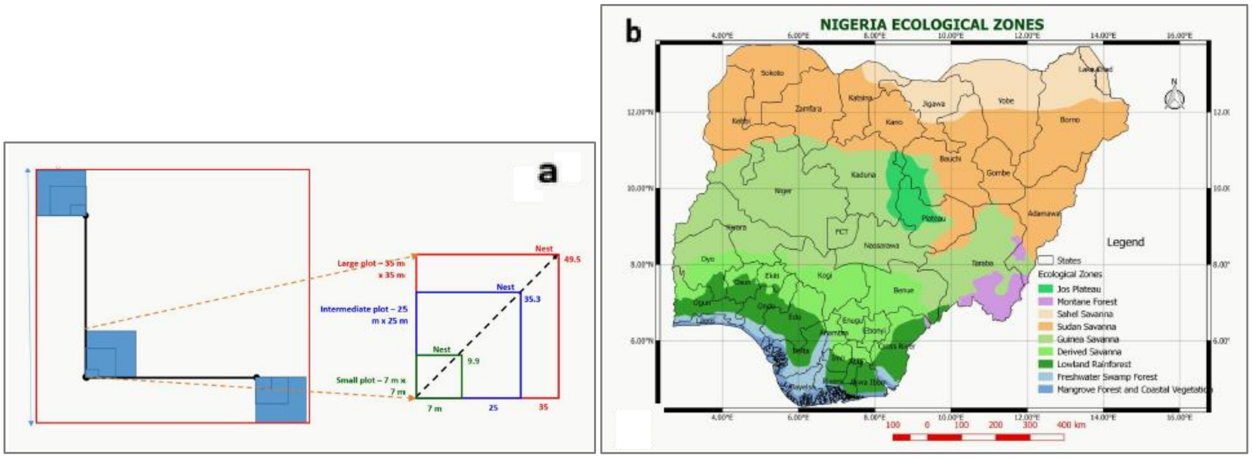

Figure 9: NFI plot design

5.1.1 Mangroves and Freshwater swamp (FWS)

The structure and dimensions of sample plots, including adaptations for Mangrove and Freshwater Swamp forests, follow the same protocols applied in the 2019 FREL. These designs were selected to reflect forest structural variability across ecological zones and to ensure accurate estimation of above-ground and deadwood biomass.

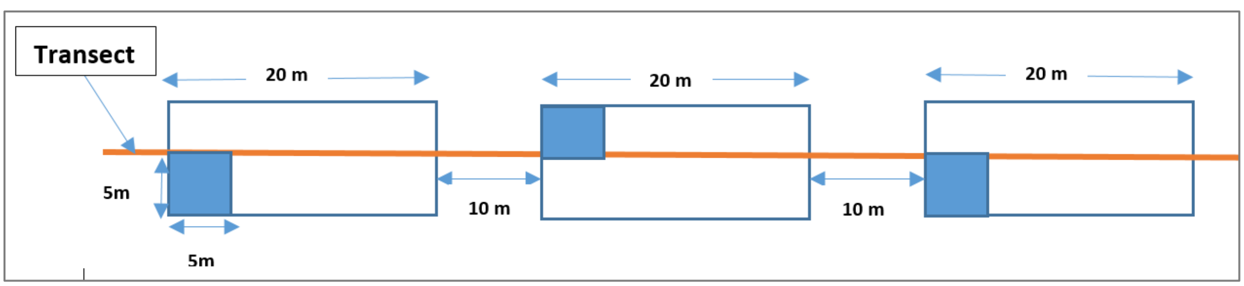

Figure 10: Transect sampling design for Mangroves and Fresh Water Swamp Forest

5.2 Biomass Components

Biomass data collection included measurements of above-ground biomass (AGB), below-ground biomass (BGB) (estimated using IPCC root-to-shoot ratios), and deadwood (standing and lying). Litter was collected in three of the ecological zones, namely lowland rainforest (60 samples), montane forest (47 samples) and Derived savanna (8 Samples) zones. Field measurement procedures, decay class assessment, and wood density application are described in detail in the 2019 FREL (Sections 6.2.4–6.2.5) and remain unchanged in this revised submission.

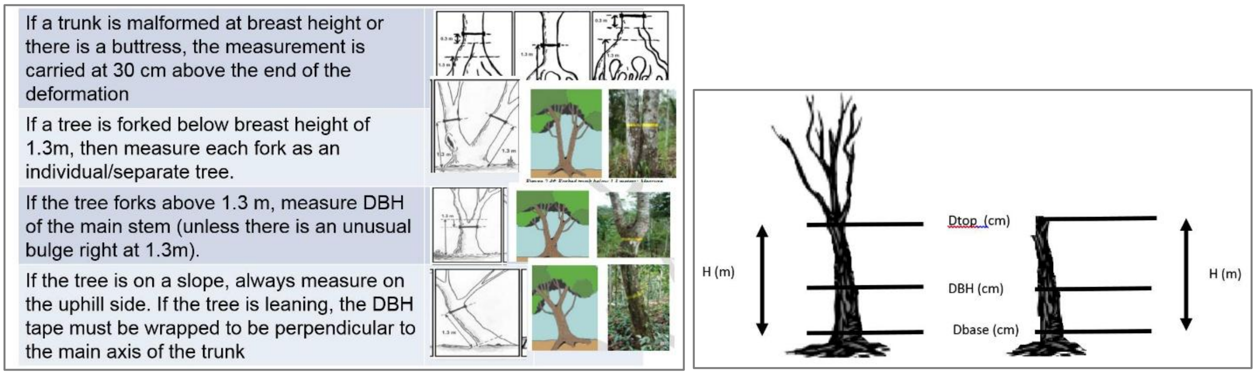

Figure 11: Live tree assessment and deadwood assessment

5.3 Carbon Stocks

Biomass estimates were converted to carbon stocks using IPCC default carbon fractions, consistent with the previous FREL. Carbon stock estimates were developed by ecological zone strata and subsequently aggregated following the same stratification scheme applied to activity data. The resulting ecological-zone-specific biomass and carbon stock estimates from the NFI continue to form the basis for emission factor calculations in this revised FREL. Above-ground and below-ground biomass estimates for live trees are summarised in Table 7.

Table 7: Biomass estimates for live trees in the different ecological zones in Nigeria

Ecological Zone	Total (AGB & BGB) Biomass (t/Ha) *(Mean ± Std Error)*	Total (AGB & BGB) Carbon Stock (tC/Ha) *(Mean ± Std Error)*	Total (AGB & BGB) CO_2 Equivalent (tCO_2/Ha) *(Mean ± Std Error)*	95% CI For CO_2 Equivalent	CI %
Mangrove and Freshwater Swamp	186.28 ± 38.62	87.55 ± 18.15	321.02 ± 66.57	130.47	40.6%
Lowland Rainforest	165.51 ± 29.87	77.79 ± 14.04	285.25 ± 51.48	100.90	35.4%
Montane Forest	249.43 ± 21.98	117.23 ± 10.33	429.84 ± 37.89	74.27	17.3%
Derived Savanna	147.32 ± 57.94	69.24 ± 27.23	253.88 ± 99.84	195.68	77.1%
Guinea Savanna	57.30 ± 10.87	26.93 ± 5.11	98.76 ± 18.72	36.69	37.2%
Sudan & Sahel Savanna	11.70 ± 2.40	5.50 ± 1.13	20.18 ± 4.16	8.15	40.4%

The results indicate that the montane forest has the highest biomass (249.43 ± 21.98 t/ha), carbon stock (117.23 ± 10.33 tC/ha), and carbon dioxide equivalent (429.84 ± 37.89 tCO_2e/ha). This is followed by the Mangrove and Freshwater Swamp and the Lowland Rainforest ecological zones.

In contrast, the Sudan and Sahel savanna zones exhibit the lowest biomass, carbon stock, and CO_2 equivalent values, reflecting their low tree density and sparse distribution of woody vegetation. These patterns are consistent with the arid climatic conditions and limited forest cover characteristic of the Sahelian region.

5.4. Emission factors for deforestation

Emission factors for deforestation were derived in accordance with IPCC guidance as the net change in carbon stocks between forest land prior to conversion and the land-use category following deforestation. Pre-deforestation Forest carbon stocks included above-ground biomass, below-ground biomass, dead wood, and litter.

Post-deforestation carbon stocks for cropland (annual and perennial) and grassland were estimated using IPCC default values. Carbon stocks for settlements, water bodies, and other land were assumed to be zero, as these land-use categories are considered to contain negligible or non-applicable terrestrial biomass pools within the AFOLU sector, in line with IPCC guidance (Table 8).

Table 8: Post-deforestation carbon stocks

AD classes	*AGB carbon stock (tC/ha)*	*CI (%)*	*Source*
Annual cropland	4.7	75%	IPCC 2019 Guidelines Vol. 4 Ch. 5 - Table 5.9 (Annual cropland)
Perennial cropland	11.1	75%	IPCC 2019 Guidelines Vol. 4 Ch. 5 - Table 5.1 (Tropical)
Grassland	4.1	75%	IPCC 2019 Guidelines Vol. 4 Ch. 6 - Table 6.4 (Tropical - Dry)
Other land	0	0%	n/a
Settlement	0	0%	n/a
Water land	0	0%	n/a

5.5 Emission Factors for degradation

Emission factors for forest degradation were estimated by combining activity data derived from sample-based area estimation with disturbance-specific carbon loss assumptions. The degradation activity dataset includes information on the main degradation drivers, allowing the application of mean relative carbon loss values by disturbance type to country-specific forest carbon stocks. Mean biomass loss percentages for selective logging, fire, and unspecified degradation were taken from literature (Heinrich, Holcomb et al., Forthcoming) and applied to pre-disturbance forest carbon stocks to estimate gross carbon losses associated with degradation events (Table 9).

Table 9: Post-disturbance mean carbon loss

AD classes	*Mean loss (%)*	*CI (%)*	*Source*
fire	44.1%	92.1%	Heinrich, Holcomb et al. (Forthcoming) - SM Table 2 (Fire)
logging	12.7%	116.6%	Heinrich, Holcomb et al. (Forthcoming) - SM Table 2 (Selective logging all)
others	26.3%	145.1%	Heinrich, Holcomb et al. (Forthcoming) - SM Table 2 (Unspecified)

To account for post-disturbance recovery, natural regrowth assumptions from the same paper were used to estimate the proportion of carbon restored over a 20-year period for degraded forests in Africa (Table 10). Net long-term emission factors for degradation were derived by averaging immediate post-disturbance carbon losses with expected carbon gains from regrowth over the 20-year period.

Table 10: Mean carbon gain after 20 years

AD classes	*Mean C after 20 yrs of regrowth (%)*	*CI (%)*	*Source*
All classes	82.3%	57.0%	Heinrich, Holcomb et al. (Forthcoming) - SM Table 4 (<20 years Africa)

6. FREL construction

Nigeria's Forest Reference Emission Level (FREL) was constructed using net emission estimates for deforestation and forest degradation over the 2017–2021 reference period, derived by combining annual activity data with emission factors from the National Forest Inventory. Uncertainty is reported at the 90% confidence interval.

6.1 Emissions from Deforestation

Annual emissions from deforestation during the 2017–2021 reference period are presented in Table 11. Deforestation constitutes the largest source of forest-sector CO_2 emissions over the reference period, with pronounced interannual variability reflecting changes in the extent and spatial distribution of forest conversion.

Table 11: Annual CO_2 Emissions from Deforestation (Reference Period 2017–2021)

	2017	2018	2019	2020	2021
Deforestation Emissions (tCO_2e)	38,040,666	64,287,011	48,767,483	51,729,475	85,195,527
Uncertainty (90% CI, CO_2e)	8,561,646	17,058,026	15,991,654	8,181,106	20,696,659
Relative Uncertainty (90% CI, %)	22.5%	26.5%	32.8%	15.8%	24.3%

Deforestation emissions ranged from approximately 38.0 million tCO_2e in 2017 to 85.2 million tCO_2e in 2021. Relative uncertainty varied between 15.8% and 32.8%, with lower uncertainty observed in years characterised by more spatially coherent deforestation patterns.

6.2 Emissions from forest degradation

Emissions from forest degradation for the 2017–2021 reference period are presented in Table 12. While substantially lower in magnitude than deforestation emissions, degradation contributes to total forest-sector emissions and is included as part of the stepwise improvement of the FREL.

In addition to CO_2, CH_4 and N_2O emissions from fire-related forest degradation are estimated following the IPCC methodological framework. The IPCC Guidelines provide a generic approach to estimate greenhouse gas emissions from fire which relates emissions of individual gases to the area burned, fuel available for combustion, combustion completeness, and gas-specific emission factors (Equation 2.27, IPCC Volume 4). In this FREL submission, CH_4 and N_2O emissions (expressed in CO_2-equivalent) are estimated for fires on Forest Land that result in degradation, using activity data on burned area and appropriate emission factors. This represents an improvement over the previous submission, which accounted only for CO_2, and reflects newly collected data on degradation drivers.

Table 12: Annual CO_2 Emissions from Degradation (Reference Period 2017–2021)

	2017	2018	2019	2020	2021
Degradation Emissions (tCO_2e)	–	852,757	381,795	709,627	1,667,570
Uncertainty (90% CI, tCO_2e)	–	403,861	172,690	292,062	324,308
Relative Uncertainty (90% CI, %)	–	47.4%	45.2%	41.2%	19.5%

Annual degradation emissions ranged from approximately 0.38 million tCO_2e to 1.67 million tCO_2e over the reference period. Relative uncertainty is higher than for deforestation, ranging from 19.5% to 47.4%, reflecting the heterogeneous and spatially fragmented nature of degradation processes and the greater complexity associated with detecting partial biomass loss.

6.3 Total Forest Emissions (2017–2021)

Total forest emissions were derived by aggregating emissions from deforestation and forest degradation. Over the 2017–2021 reference period, total annual emissions ranged from approximately 38.0 million tCO_2e to 87.2 million tCO_2e, as shown in Figure 13.

Table 13: Total Forest Emissions (Reference Period 2017–2021)

Year	Total Emissions (TCO_2e)	Uncertainty (90% CI, TCO_2e)	Relative Uncertainty (%)
2017	38,040,666	8,561,646	22.5
2018	65,139,768	17,461,887	26.8
2019	49,149,277	16,164,344	32.9
2020	52,439,102	8,473,168	16.2
2021	87,246,352	21,020,967	24.1

6.4 Derivation of the Forest Reference Emission Level (FREL)

Nigeria's Revised Forest Reference Emission Level (FREL) is defined as the average annual total forest-sector emissions from deforestation and forest degradation over the 2017–2021 reference period, in accordance with Decision 12/CP.17 and relevant IPCC guidance.

The revised FREL was derived by aggregating annual emissions from deforestation and forest degradation for each year within the reference period and calculating their arithmetic mean. This approach ensures that the reference level reflects interannual variability in forest-related emissions while providing a stable benchmark for future performance assessment.

Based on the results presented in Sections 5.8.3, Nigeria's revised FREL is estimated at: 58,403,033 tCO_2e per year

This value constitutes Nigeria's benchmark emission level for the assessment of future emissions and potential emission reductions under the UNFCCC REDD+ framework.

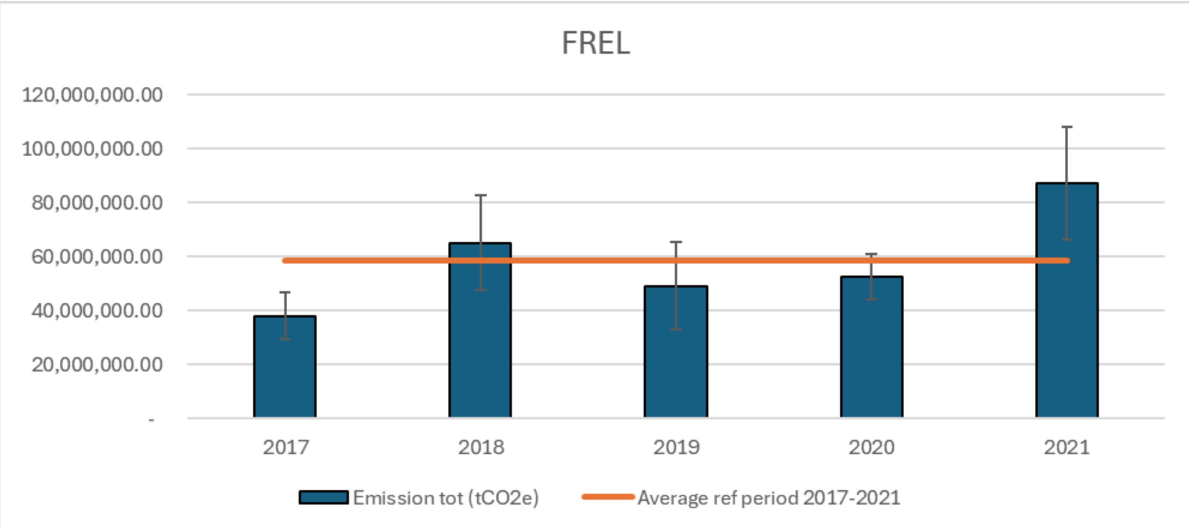

Figure 12: Annual emissions and their averages over the reference period

6.5 Uncertainty calculations

Uncertainty in the FREL is quantified by combining the uncertainties of activity data (AD) and emission/removal factors (EFs). Once the AD uncertainty has been estimated, the overall FREL uncertainty is calculated following the IPCC 2019 Refinement (Equations 3.1 and 3.2, Volume 2). This approach assumes that AD and EF uncertainties are independent and follows standard error propagation methods for multiplication (Equation 3) and addition and subtraction (Equation 4), allowing the derivation of an aggregated uncertainty that reflects the combined effect of input data variability on total emissions and removals.

$$U_{total} = \sqrt{U_1^2 + \ldots U_i^2 + \ldots + U_n^2}$$ **Equation 3**

Where:

U_{total} = the percentage uncertainty in the product of the quantities (half the 95 percent confidence interval divided by the total and expressed as a percentage)

U_i = the percentage uncertainties associated with each of the quantities

$$U_{total} = \frac{\sqrt{(U_1 * x_1)^2 + \ldots + (U_i * x_i)^2 + \ldots + (U_n * x_n)^2}}{|X_1 + \ldots + X_i + \ldots + X_n|}$$ **Equation 4**

Where:

U_{total} = the percentage uncertainty in the sum of the quantities (half the 95 percent confidence interval divided by the total (i.e., mean) and expressed as a percentage)

x_i = quantities to be combined; x_i may be a positive or negative number

U_i = the percentage uncertainties associated with each of the quantities

7. Transparent, Complete, Consistent, and Accurate Information

In accordance with Decision 12/CP.17, this revised Forest Reference Emission Level (FREL) has been prepared to ensure transparency, completeness, consistency, and accuracy in the information provided.

All methodologies and processes applied in the estimation of activity data and emission factors are documented in a transparent manner. Detailed methodological descriptions are provided in the main body of this document, with supporting information, intermediate results, and technical details included in the appendices. Spatial datasets, metadata, and maps used for activity data estimation are fully referenced and stored within a national spatial database, ensuring traceability of inputs. Similarly, emission factor calculations derived from National Forest Inventory (NFI) data are fully documented, with calculation spreadsheets retained and summary results presented in the appendices.

The information presented in this revised FREL is complete and allows for the reconstruction of the reference level, consistent with Annex I of Decision 12/CP.17. All datasets, assumptions, parameters, and methodological choices applied in constructing the FREL are nationally developed and documented. Where data or methodological approaches remain unchanged from the 2019 national FREL, explicit references are made to that submission to ensure continuity and avoid unnecessary duplication. All relevant information will be made publicly available through appropriate national platforms.

Consistency has been maintained with Nigeria's national greenhouse gas inventory system, in line with paragraph 8 of Decision 12/CP.17. The revised FREL applies a clear and consistent forest definition and methodological framework that aligns with improvements made since earlier national greenhouse gas inventory submissions, which were constrained by data availability and forest definition limitations. Methodological consistency is also preserved across FREL submissions to ensure comparability over time.

Accuracy has been addressed through the application of robust methods for activity data generation and validation. Activity data were derived using consistent land-use change detection approaches, supported by accuracy assessment procedures based on independently generated reference data.

Comparative analyses of available global datasets informed dataset selection, and accuracy assessments were conducted following established good practice. These procedures strengthen confidence in the reliability of the activity data used in the revised FREL.

Overall, the revised FREL reflects continuous methodological improvement while maintaining transparency, completeness, consistency, and accuracy, thereby providing a robust and credible reference for future REDD+ results-based assessments.

8. Areas for future improvements

Consistent with the stepwise approach encouraged by the UNFCCC and applied in Nigeria's 2019 Forest Reference Emission Level, the revised FREL expands the scope of REDD+ activities to include emissions from forest degradation, in addition to deforestation. This reflects improvements in the availability of activity data and national capacity for forest monitoring.

Enhancement of forest carbon stocks was not included in the current revised FREL. Although regrowth was considered during the design of the activity data collection, the sampling intensity achieved was not sufficient to support a robust national-level estimation of afforestation, reforestation, and regrowth. As such, enhancement activities were excluded to avoid underestimation or misrepresentation.

Emission factors applied in the revised FREL were derived from existing National Forest Inventory (NFI) data, consistent with the approach used in the previous submission. In the absence of newly available nationally representative forest inventory data, these emission factors were retained to ensure methodological consistency and comparability. Future improvements to the FREL may include the enhancement activity and the use of updated NFI data, subject to data availability and methodological feasibility.

9. References

Bey, A., Sánchez-Paus Díaz, A., Maniatis, D., Marchi, G., Mollicone, D., Ricci, S., Bastin, J.F., Moore, R., Federici, S., Rezende, M. and Patriarca, C., 2016. Collect earth: Land use and land cover assessment through augmented visual interpretation. Remote Sensing, 8(10), p.807.

Cochran, W.G. (1977). Sampling Techniques (3rd ed.). John Wiley & Sons.

FAO (2016). System for Earth Observation Data Access, Processing and Analysis for Land Monitoring (SEPAL) Technical Manual. FAO, Rome.

FAO (2021). Collect Earth and Collect Earth Online Technical Documentation. Open Foris Initiative, Rome.

FAO (2020). Nigeria - National Forest (carbon) Inventory. Abuja. https://doi.org/10.4060/cb1328en

Heinrich, Holcomb et al. (Forthcoming). A multi-data synthesis of carbon losses and gains from tropical moist forest degradation and regeneration.

IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4: Agriculture, Forestry and Other Land Use (AFOLU).

IPCC (2019). 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

Olofsson, P., Foody, G.M., Herold, M., Stehman, S.V., Woodcock, C.E., & Wulder, M.A. (2014). “Good practices for estimating area and assessing accuracy of land change.” Remote Sensing of Environment, 148: 42–57.

Stehman, S.V. (2009). “Design, implementation, and evaluation of sampling strategies for land-cover change.” Remote Sensing of Environment, 113(1): 25–35.

FORMECU, 1998 The Assessment of Vegetation and Land Use Changes in Nigeria between 1976/78 and 1993/95. Report prepared by Geomatics International of Canada for FORMECU of the Federal Department of Forestry, Abuja, Nigeria

Appendix 1 - LULUC Classes, 2024

1.1 Forestland

This category includes all land with woody vegetation consistent with thresholds used to define forest land in the national GHG inventory, sub-divided into managed and unmanaged, and by ecosystem type as specified in the IPCC Guidelines3. It also includes systems with vegetation that currently fall below, but are expected to exceed, the threshold of the forest land category.

Nigeria Forest definition: “An ecological community predominated by trees and other layers of woody plants with a minimum area of **0.5 ha**, a minimum tree height of **3-metres**, and a **minimum tree canopy cover of 15%,** or stands with potentials to reach the above thresholds in situ".

Explanatory variables

- It does not include land that is predominantly under agricultural or urban land use.
- Forest is determined both by the presence of forest trees and the absence of other predominant land uses.
- The trees should be able to reach a minimum height of 3 meters in situ.
- Includes, firebreaks, and other small open areas; forest in national parks, nature reserves, and other protected areas such as those of specific environmental, scientific, historical, cultural, or spiritual interest.
- It **includes** the forest plantation for restoration purposes. Young natural stands and all plantations established for forestry purposes (conservation, restoration, protection, timber, watershed protection, carbon sequestration etc.) which have yet to reach a crown density of 15 percent or tree height of 3 m are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention or natural causes, but which are expected to revert to forest." (FAO/UNEP, 1999)
- **Excludes** tree stands in **agricultural production systems**, such as fruit tree plantations, cocoa, cashew, gum arabica, rubber, oil palm plantations, olive orchards, and agroforestry systems when crops are grown under tree cover.

Forest Dense

Forest, dense refers to areas of natural forest cover with a high canopy density, specifically where the canopy cover is 70% or greater. These forests are typically characterized by minimal human disturbance and maintain a relatively intact ecosystem structure, offering significant carbon sequestration potential and biodiversity conservation.

Figure 13: Examples of Dense Forest in Nigeria

Forest Sparse

Forest, sparse, refers to forested areas where the canopy cover ranges between 15% and less than 70%. These forests have often been subjected to various degrees of human activity, such as logging, agricultural encroachment, or other forms of disturbance, leading to a reduction in canopy density and overall ecological health)

Figure 14: Examples of Sparse Forest in Nigeria

Forest Plantation

Commercial forest is defined as any homogeneous tree planting or forest regeneration with the purpose of timber, fiber, fruit or tree sap harvest for a commercial local, national or international market (Source: ART- TREES standards). Teak, Gmelina, Eucalyptus, Azadirachta indica (Neem), Khaya spp.

Most forest plantations in Nigeria are considered commercial by default. However, there are several afforestation programs the purpose of restoration, climate change mitigation, biodiversity conservation.

Mangrove/Freshwater Swamp Forest

Mangrove/Freshwater Swamp Forest refers to a mosaic of marine and freshwater-associated vegetation types typically found along coastlines, creeks, estuaries, riverbanks, and marshy areas. These forests may occur as pure stands or in mixtures with species such as Nypa palm, Raphia, hydrophytes and other wetland vegetation. Canopy closure ranges from 15% to 100%.

Figure 15: Costal Mangrove Forest (Google Earth Pro)

1.2 Cropland

This category includes arable and tillage land, and agroforestry systems where vegetation falls below the thresholds used for the forest land category, consistent with the selection of national definitions.

Explanatory variables

- Includes arable and tillable land, rice fields, and agroforestry systems
- Cropland includes all annual and perennial crops.
- Annual crops include cereals, oils seeds, vegetables, root crops and forages.

- Perennial crops in combination with herbaceous crops (e.g., agroforestry) or as orchards, vineyards and plantations such as cashew, plantain, cocoa, coffee, tea, coconut, bananas
- Arable land, which is normally used for cultivation of annual crops, but which is temporarily used for forage crops or grazing as part of an annual crop-pasture rotation (mixed system) is included under cropland.
- Fellow land with and without trees

Arable Cropland

Arable Cropland refers to land that is regularly cultivated and used for the production of annual or short-cycle crops, such as cereals, legumes, vegetables, and tubers. In Nigeria, this includes both rainfed and irrigated farms. It excludes land that's under permanent crops like cocoa, rubber, cashew, tea, coffee or oil palm, and land left fallow for a period of 5years.

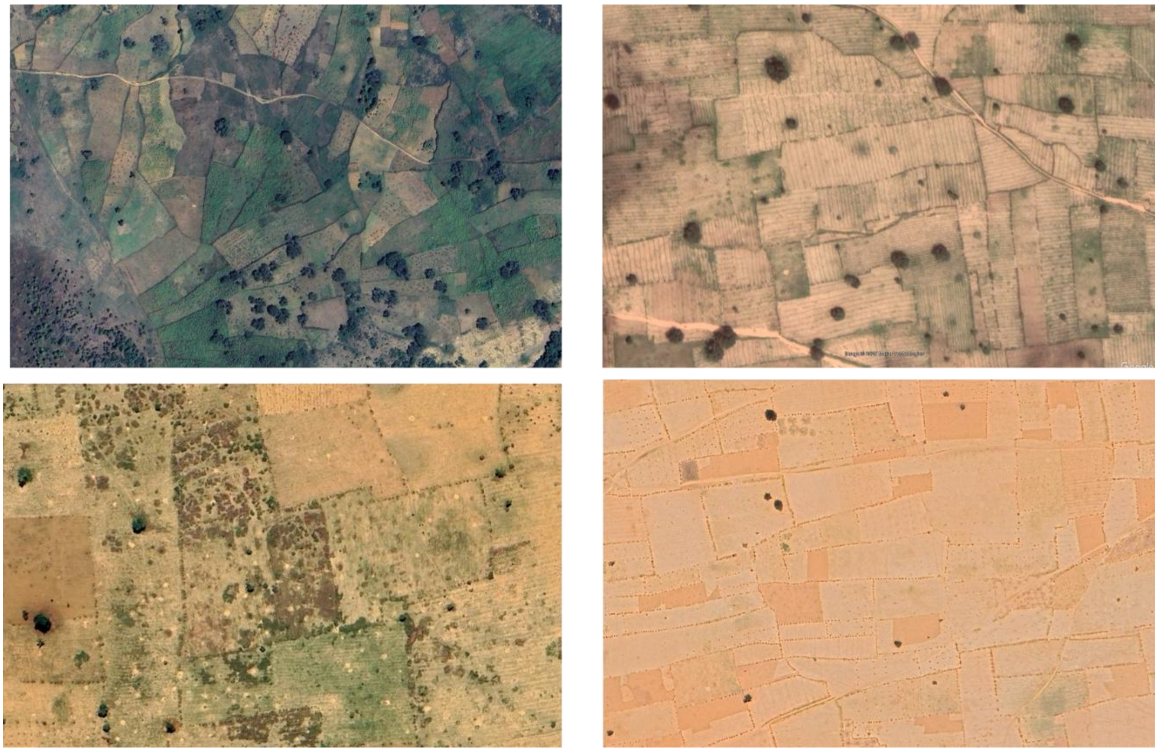

Figure 16: Arable cropland in northern Nigeria (Google Earth Pro)

Fallow land

Fallow Land refers to agricultural land that is temporarily left uncultivated to restore soil fertility and allow ecological recovery. It may be covered with natural vegetation and is typically intended for future cultivation. In some cases, fallow land can be identified by signs of past agricultural use, presence of natural regrowth, which is often used for land clearing or weed control.

- Fallow land plots typically exhibit irregular shapes, unlike the more uniform parcels of permanent croplands.
- They are often situated near forested areas, sometimes within fragmented forests and tend to be associated with nearby settlements.

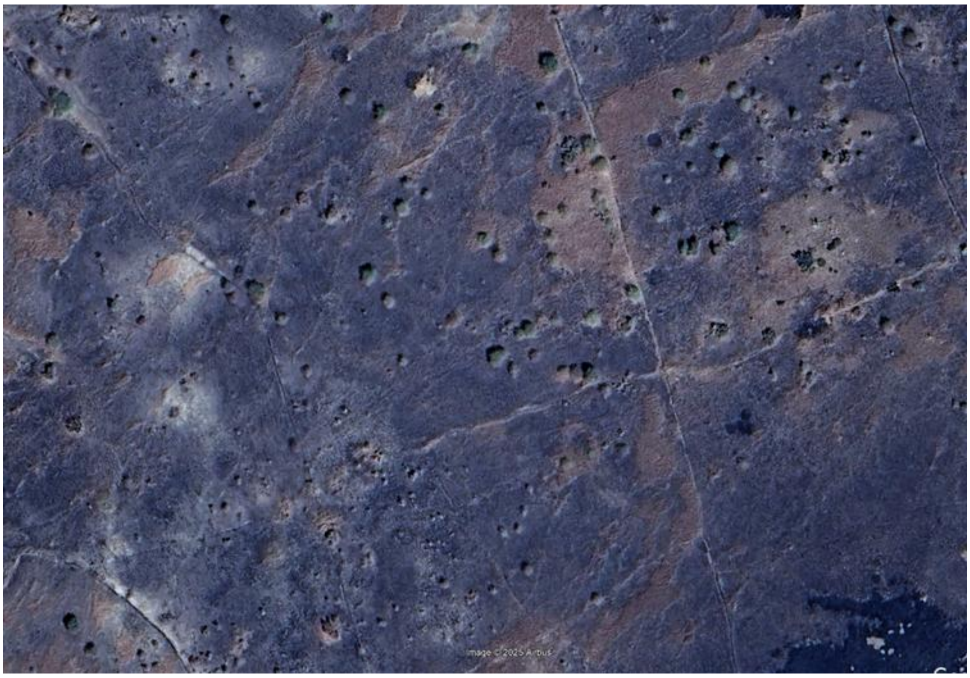

Figure 17: Sign of Fires in Cropland in southern Nigeria (Google Earth Pro)

Permanent Crops

Primarily consists of fruit tree crops such as cocoa, rubber, oil palm, tea, gum Arabic, orchards, coffee, and cashew. The land is dominated by crops for commercial or subsistence purposes, either as monoculture plantations or integrated with other crops.

Agroforestry

Agroforestry is the cultivation of agricultural crops both annual and permanent with the integration of forest trees. Presence of trees either scattered or clustered within a cropland.

1.3 Grassland

This category includes rangelands and pastureland that is not considered as cropland. It also includes ecosystems with vegetation that fall below the canopy cover 15%. The category also includes all grassland from wild lands to recreational areas as well as Silvi-pastural systems, subdivided into managed and unmanaged consistent with national definitions.

Explanatory variables

- Grasslands can vary greatly in their degree and intensity of management, from extensively managed rangelands and savannahs where animal stocking rates and fire regimes are the main management variables, to intensively managed systems (e.g., with fertilization, irrigation, species changes), including continuous pasture and hay land.
- Grasslands generally have vegetation dominated by perennial grasses, with grazing as the predominant land use, and are distinguished from "forest" by having a tree canopy cover of less than 15 percent.
- Grasslands include rangelands and pastureland that are not considered Cropland including systems with woody vegetation and other non-grass vegetation such as herbs and shrubs (shrubs are trees with height of less than 3 meters).
- Includes Savanna or savannah, mixed woodland grassland ecosystem

Natural Grassland

Natural Grassland refers to open areas dominated by native grasses, herbaceous plants, and meadows, with less than 15% tree cover and dominated by shrubs.

Figure 18: Natural Grassland with some woody vegetation (Google Earth Pro)

Savanna Woodland (non-forest)

Savanna Woodland (non-forest) refers to a savanna landscape characterized by a mix of grassland and scattered trees or shrubs, where the tree canopy cover is less than 15%, mostly dominated by drought-resistant vegetation and dominated by shrubs and herbaceous vegetation.

Figure 19: Savanna woodland with presence of Shrub and herbs (Google Earth Pro)

1.4 Wetlands

This category includes land that is covered or saturated by water for all or part of the year (e.g., peatland) does not fall into the forest land, cropland, grassland or settlements categories. It includes reservoirs as managed sub-division and natural rivers and lakes as unmanaged subdivisions.

Explanatory variables

- Guidance is restricted to Managed Wetlands where the water table is artificially changed (e.g., drained or raised) or wetlands created through human activity (i.e., damming a river)
- Reservoirs or impoundments, for energy production e.g., Dam irrigation, navigation, or recreation (Flooded Land)
- All water bodies, including seasonal water bodies, swamps.
- Wetlands Natural or artificial ponds,

- Rivers, Lakes and streams, waterfalls

Wetland

Ramsar Convention (international standard): Wetlands are areas of marsh, fen, or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish, or salt, including areas of marine water the depth of which at low tide does not exceed six meters.

Water Bodies

Water bodies are natural or artificial accumulations of water, either static or flowing, that occupy a significant area of the land surface. This includes rivers, lakes, reservoirs, and coastal waters, water Dams, pounds.

Water bodies can appear in different colors in satellite imagery depending on the sensor used, band combinations applied, and the time of year the image was captured. Clear lakes may appear dark blue or black in true color composites. Turbid rivers can show up as brown or green due to suspended sediments. Algae-rich ponds may appear bright green in summer months.

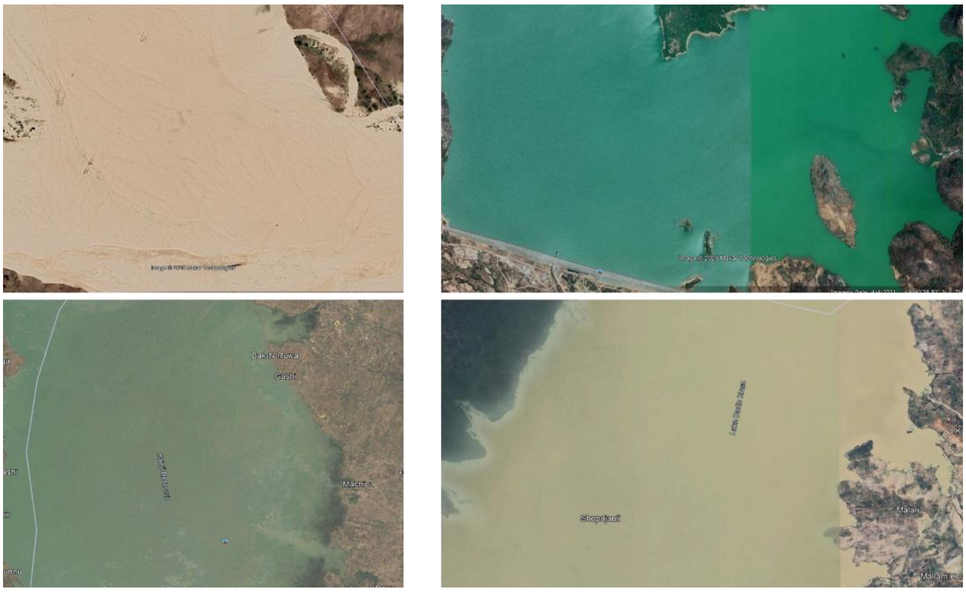

Figure 20: Few examples of water bodies (Google Earth Pro)

1.5 Settlements

This category includes all developed land, including transportation infrastructure and human settlements of any size, unless they are already included under other categories.

Explanatory variables

- Settlements include residential, transportation, commercial, and production (commercial, manufacturing) infrastructure of any size, unless it is already included under other land-use categories.
- The land-use category settlements include soils, herbaceous perennial vegetation such as turf grass and garden plants, trees in rural settlements, homestead gardens and urban areas.
- Examples of settlements include land along streets, roads in residential (rural and urban) and commercial lawns, in public and private gardens, in golf courses and athletic fields, e.g., cricket field and in parks, provided such land is functionally or administratively associated with cities, villages or other settlement types and is not accounted for in another land-use category.
- Airports, factories
- Mining sites, Active Mine dump generally, but also include the dumps if not active.

Figure 21: Few examples of Settlements and built-up area (Google Earth Pro)

1.6 Other land

This category includes bare soil, rock, ice, and all unmanaged land areas that do not fall into any of the other five categories. It allows the total of identified land areas to match the national area, where data are available.

Explanatory variables

- Other Land includes bare soil, rock, ice, and all land areas that do not fall into any of the other five land-use categories.
- Other Land is often unmanaged

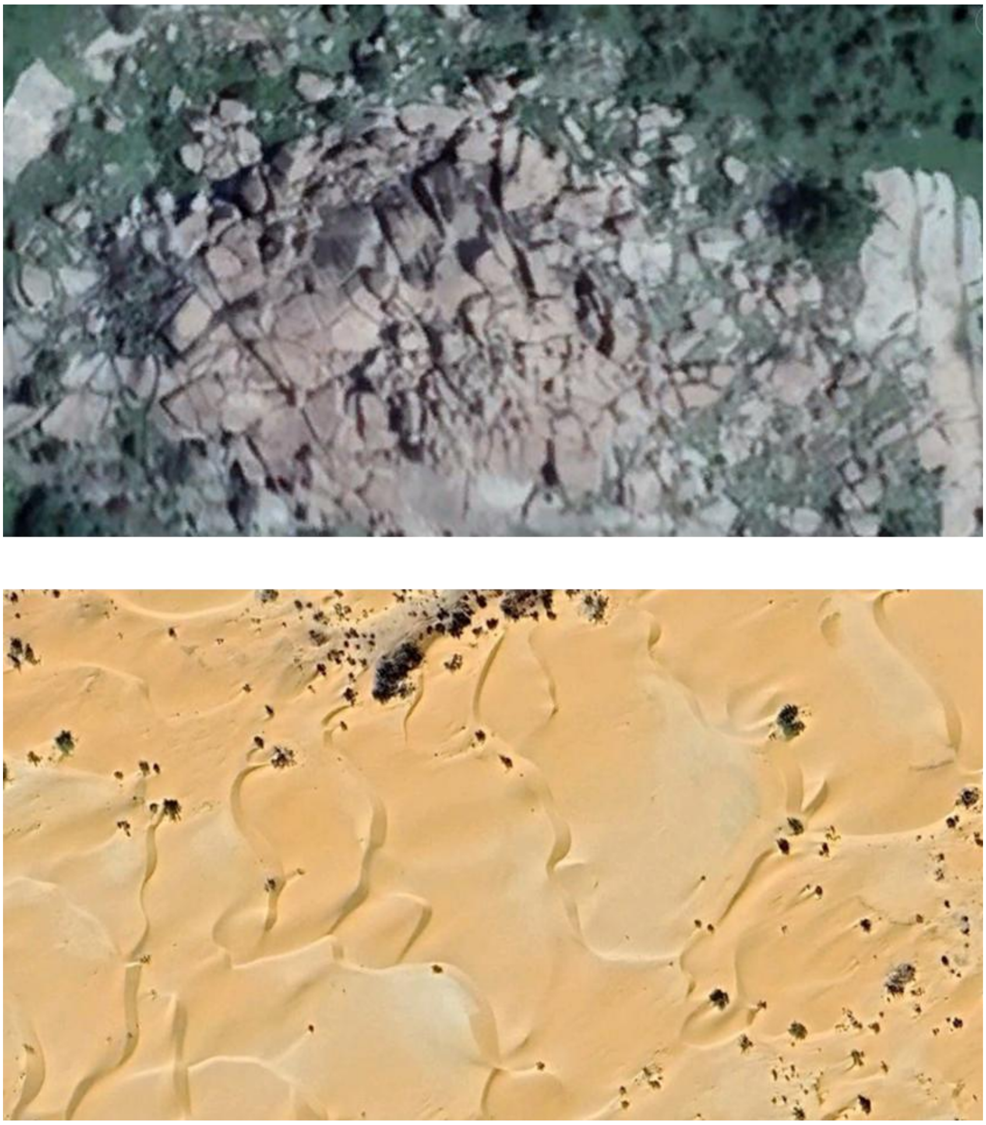

Figure 22: Examples of other classes: Bare soil, rocks (Google Earth Pro)

Appendix 2 - Key Elements of Image Interpretation

There are seven key elements to consider when interpreting satellite imagery for data collection. These elements help in accurately identifying and analysing land features. A brief explanation of each is provided below.

Tone (Brightness): refers to the relative brightness or colour of a feature in satellite imagery. In forestry, healthy forest canopies reflect strongly in the Near Infrared (NIR) band, appearing bright. In contrast, burnt or degraded areas reflect less in the Shortwave Infrared (SWIR), making them appear darker.

Texture: refers to the visual pattern or variation in tone across an image, appearing coarse or smooth. Old-growth forests typically show a coarse texture due to diverse canopy structure, while plantations often appear smoother and more uniform.

Shadow: provide clues about the height and shape of objects in satellite imagery. Tall trees cast long shadows, helping to estimate canopy height and distinguish them from shrubs or herbs.

Shape: refers to the recognizable form of features in imagery. Regular, rectangular plots often indicate plantations or agricultural fields, while irregular, complex shapes are typical of natural forests. Linear shapes represent roads or rivers.

Size: refers to the relative dimensions of features in an image. Small clearings often indicate selective logging, while large, uniform blocks typically reflect commercial deforestation or plantations. Large patches may also represent urban areas, while small, scattered plots can indicate smallholder farms or rural settlements.

Pattern: refers to the spatial arrangement of features in an image. Linear patterns often indicate logging roads or rivers, while checkerboard patterns suggest timber harvesting or agricultural fields. Clustered or dispersed patterns represent settlements, orchards, or natural vegetation patches.

Association: describes the relationship between features and their surrounding environment. For example, forests near rivers often include riparian vegetation, while deforested areas frequently occur close to roads or settlements. Agricultural fields are usually found near water sources, and urban areas tend to cluster around transportation networks.

Appendix 3 - Examples of Change Classes

3.1 Deforestation Example

A change from forest to non-forest LULC refers to a permanent conversion where the land no longer functions as a forest. Temporary canopy loss such as logging or natural disturbance is not included if the land use remains forest. However, if tree cover drops below the defined canopy threshold and the land use no longer qualifies as forest, it is considered a transition to non-forest LULC.

Figure 23 represents an example of deforestation plot over the reference period. Plot was observed stable until 2014 and first change is observed in 2018, Forest land was converted to cropland.

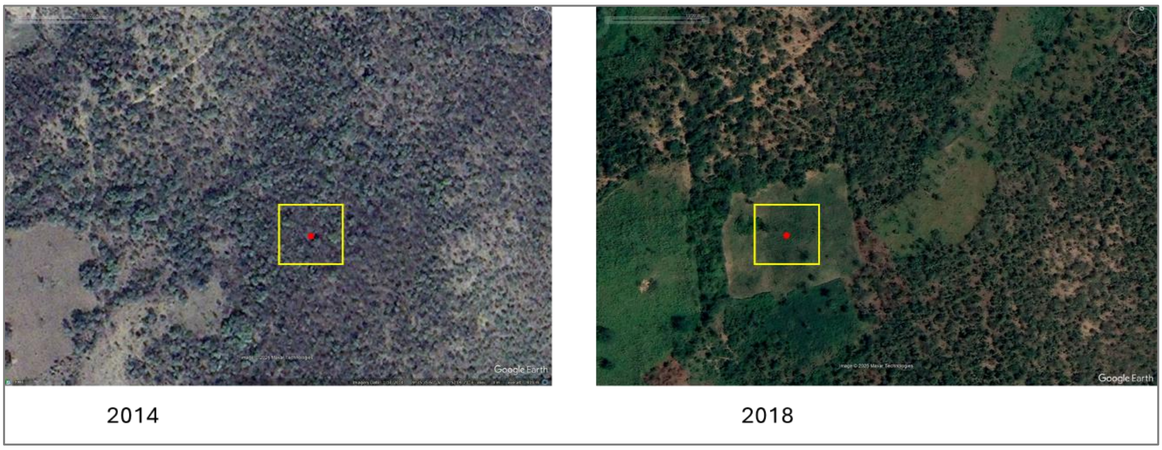

Figure 23: Example of deforestation, over the reference period (Google Earth Pro)

3.2 Forest Degradation

Forest degradation refers to changes within forested areas where the land continues to meet the definition of forest, and no change in land use occurs. These changes often involve a decline in forest quality, such as reduced canopy density, biomass, without crossing the threshold into non-forest status.

Figure 24 represents an example of forest degradation plot. In 2008, the area within the yellow box exhibited dense canopy cover and by 2023, there is a noticeable reduction in canopy, especially in the lower left corner of the plot. However, the tree cover remains above 15%, still meeting the forest definition criteria. Therefore, this change is classified as forest degradation rather than deforestation.

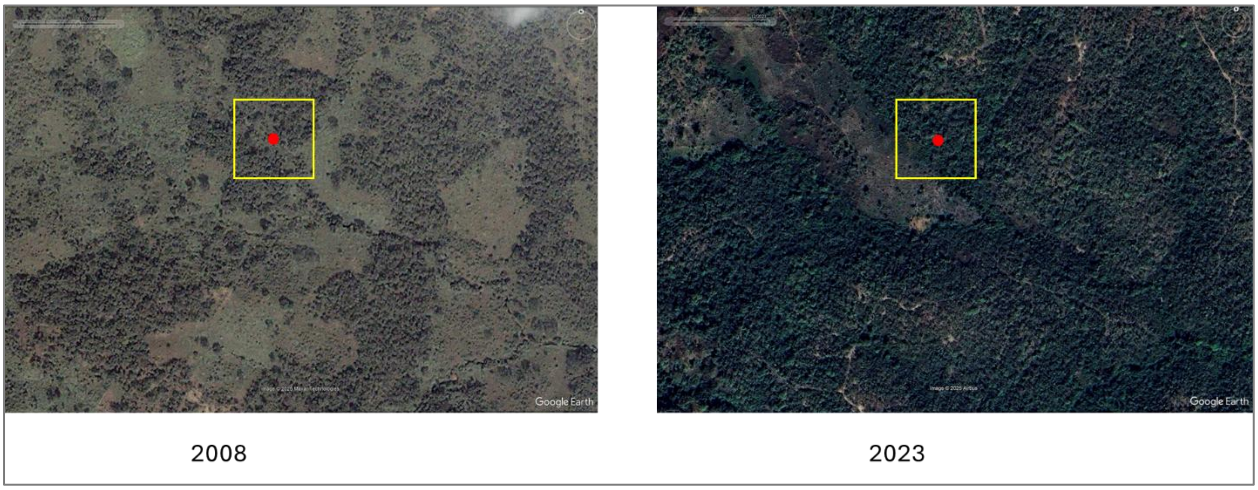

Figure 24: Example of forest degradation plot (Google Earth Pro)

3.3 Forest Enhancement

Enhancement of forest carbon stocks includes both enrichment in carbon stocks in forest remaining forest, as well as enrichment in carbon stocks through afforestation/reforestation and natural regeneration of forest.

Figure 25 shows an example of forest enhancement. This example demonstrates forest enhancement, where the area was initially classified as non-forest at the beginning of the monitoring period but showed noticeable increase in tree cover and met forest criteria by the end of the period in 2024.

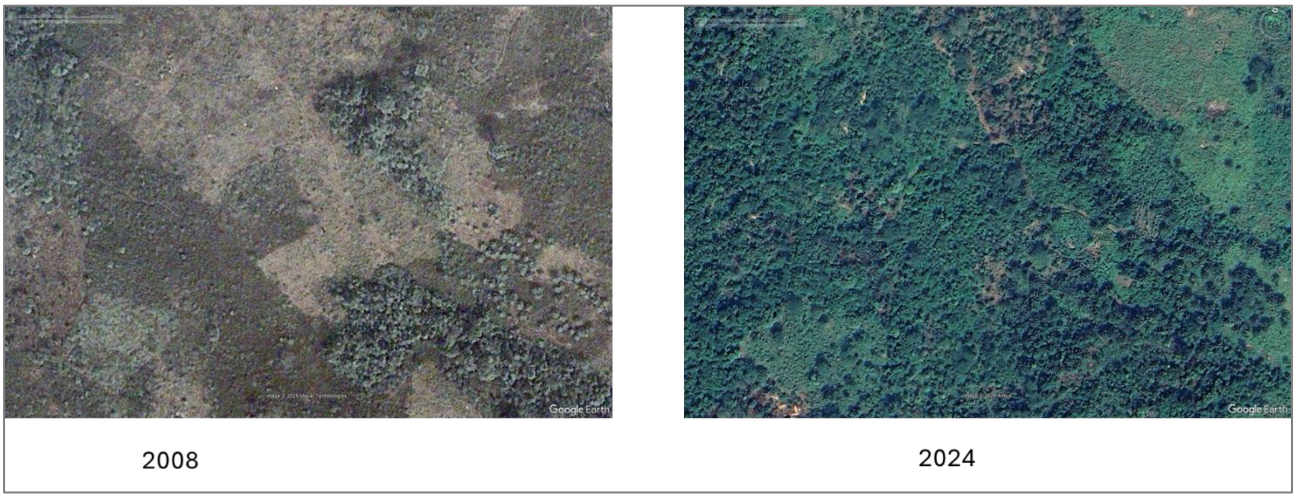

Figure 25: Example of forest enhancement (Google Earth Pro)

Table 14: Classification Scheme from the NFMS Standard Operating Procedures (SOPs)

IPCC	Sub-Class Name	OPERATIONAL Description	Descriptive definition	Source
F	Dense Forest	Natural forests with canopy cover ≥70%, Min extent of 0.5ha	Minimally disturbed mostly in the southern part etc.	FREL: Undisturbed Forest (UF); SOP: Dense Forest
F	Sparse Forest	Natural forests with canopy cover 15–69%,-min extent of 0.5 ha		FREL: Disturbed Forest (DF); SOP: Sparse Forest
F	Forest Plantation: commercial	Planted forests		FREL: Forest Plantation (FP)
F	Forest plantation: noncommercial			
F	Mangrove/Freshwater Swamp Forest	Forests in tidal/brackish zones considered forest by definition Crown cover: >=15% Swamp area with presence of vegetation, meeting Forest definition criteria.		FREL: FWS; SOP: Dense/Sparse Forest
C	Arable Cropland	Land cultivated for seasonal or annual crops		FREL: Arable Land (AL); SOP: Cropland
C	Fallow land	>= 5 year		
C	Tree Crop Plantation / Agroforestry	Cocoa, rubber, or oil palm, coffee, cashew, plantations	Mainly fruits Trees, but might also include Timber species	FREL: TCP; SOP: Tree crop
G	Natural Grassland	Open grasslands with <15% tree cover, found in savanna areas. Min extent of 0.5ha		FREL: Grassland (G); SOP: Grassland
G	Savanna Woodland (non-forest)	Savanna with scattered trees <15% canopy cover. Min extent of 0.5 ha including shrubland		FREL: Savanna Woodland (SW), if canopy <15%
W	Water Bodies	Rivers, lakes, reservoirs, coastal waters		FREL/SOP: Water Body (WB)
W	Peatland			
S		Cities and major urban centres, scattered rural settlements and smaller towns, mining area/activities		FREL: Settlements (S); SOP: Settlement
O	Bare Land	Areas with no vegetation: exposed soil, rock, dunes, eroded zones		FREL: Bare Surfaces (BS); SOP: Other Land

Driver of Degradation

- Logging
- Fuelwood & Charcoal
- Flooding
- Soil Erosion
- Fire

Drivers of Enhancement

- A/R programs = Afforestation and reforestation programs
- NR of secondary forest = Natural regeneration of secondary forests
- REDD+ pilot sites = Conservation initiatives (e.g., REDD+ pilot sites)
- CFM and Conservation = Community Forest management and conservation efforts
- SFM practices = Sustainable Forest management practices
- Tree Plantation = Tree planting campaigns by government and NGOs

Appendix 4 - List of Team members

Table 15: Members of Nigeria Remote sensing Team Participated in AD collection

Name	***Gender***	***Designation***	***Organization***
Ebunoluwa Ajagun	F	Assistant Chief Forest Officer	Federal Department of Forestry, Federal Ministry of Environment
Chioma Doris Okafor	F	Principal Scientific Officer	Federal Department of Forestry, Federal Ministry of Environment
Henry Karshima	M	Assistant Chief Forest Officer	Federal Department of Forestry, Federal Ministry of Environment
Abdullahi Yakubu	M	Principal Forest Officer	Federal Department of Forestry, Federal Ministry of Environment
Ralph Adewoye	M	Senior Research Fellow	Forestry Research Institute of Nigeria, Federal Ministry of Environment
Abbas Abdulwahab	M	Forest Officer	Federal Department of Forestry, Federal Ministry of Environment
Chinwe Adindu	F	Principal Forest Officer	National Council on Climate Change
Babatunde Ibrahim	M	Lecturer	Department of Surveying & Geo-informatics, Kogi State Polytechnic, Lokoja.
Bridget Nkor	F	Retired Director	Cross River State Forestry Commission
Asuquo Okon	M	Consultant	FAO, Nigeria
Ademola Orogun	M	Senior Forest Officer	Ondo State Department of Forestry
Mayowa Adedokun	M	Student	Nasarawa State University
Emmanuel Omoniyi	M	Student	Nasarawa State University
Tamara Madaki	F	Assistant	AYGeospatial
Abubakar Tanimu Abubakar	M	Senior Scientific Officer	National Space and Research Development Agency
Clement Adole	M	Geospatial Analyst	Office for Strategic Preparedness and Resilience (OSPRE) National Early Warning Centre
Ayodele Samuel John	M	Consultant	Landell Mills

Table 16: Management and Technical Support Team

No.	Name	Gender	Role	Institution
1	Marieke Sandker	F	Technical Expert	FAO
2	Naila Yasmin	F	Remote Sensing and GIS Expert	FAO
3	Alessandro Albani	M	MRV Specialist	FAO
4	Andreas Vollrath	M	Remote Sensing and GIS Expert	FAO
5	Mrs. Omotenioye Majekodunmi	F	Director-General National Council on Climate Change (NCCC)/United Nations Framework Convention on Climate Change (UNFCCC) Focal Point	NCCC
6	Dr. Halima Bawa - Bwari	F	Director Forestry	Department of Forestry, Federal Ministry of Environment
7	Mr. Christopher Aiwuyo	M	National Coordinator REDD+ Secretariat	Department of Forestry, Federal Ministry of Environment
8	Ebunoluwa Ajagun	F	MRV and GHG Specialist	Department of Forestry, Federal Ministry of Environment