THE REPUBLIC OF SUDAN

FOREST NATIONAL CORPORATION

FOREST REFERENCE LEVEL SUBMISSION TO THE UNFCCC

2025

FOREWARD

The Republic of Sudan (RoS) is one of the most vulnerable countries to climate change and its devastating impacts and therefore, highly committed to the international cooperation on addressing this phenomenon. REDD+ is among the top priority programmes for RoS to participate in the global mitigation efforts and to build resilience in its land sector, which host about 70% the population.

RoS is integrating the global REDD+ objectives into its national climate change related plans and strategies. The current NDC (2021) aims towards implementing low carbon development interventions in three sectors - energy, forestry and waste. Sustainable management of degraded forest and the Gum Arabic belt; afforestation and restoration of degraded agriculture lands; and restoration/conservation of mangrove forests along Red Sea coast; are among the key contributions included in RoS's NDC (2021).

In 2021 RoS adopted a National REDD+ Strategy (NRS), with the objective of maximizing carbon and non-carbon benefits through improved sustainable natural resources management. The NRS support RoS efforts to achieve REDD+ objective and contribute to the global climate change mitigation in the context of sustainable development. In this context, the preparation of this forest reference level (FRL) will support and enable effective implementation of the national REDD+ Strategy (NRS), RoS's NDCs, monitoring and reporting on the forest sector mitigation actions.

The submission of this FRL is a clear demonstration of RoS commitment and keen interest to undertake ambition climate mitigation actions and transition its forest sector towards a low emission, sustainable development pathway.

Anwar Abdelhameid
Director General, Forest National Corporation

ACKNOWLEDGEMENT

The preparation of this National Forest Reference Level (FRL) of Republic of Sudan (RoS) under the current war circumstances demonstrate a high level of determination, dedication and commitment of Sudanese Government institutions and experts to pursue their international obligations.

The successful completion of this submission is a result of collaboration and contribution of many national institutions and experts, without their dedication it would have been impossible to achieve this success.

I would like to acknowledge with much gratitude the crucial rule of the National REDD+ Steering Committee for the wise guidance they provided throughout the preparation of the national FRL.

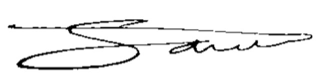
My sincere thanks and gratitude to the members of the FRL Taskforce and Remote Sensing Team for their valuable contributions, dedication and commitment to successfully achieving all their assigned tasks and activities despite the difficulties in communications, internet connection and access to offices.

I am greatly indebted to the national and international consultants who provided the needed technical support and backstopping to the various stages of the FRL preparation.

I am extremely grateful to Mr Anwar Abdelhamied, the Director General of the Forest National Corporation (FNC) who provided full support and guidance which enable the REDD PMU to successfully complete this FRL submission despite the challenging war circumstances.

I would like to present my warmest thanks and gratitude to all colleagues of FNC staff, specially colleagues in the different States of the country who provided expert input and supported the data collection phase of this FRL preparation, they really deserved special thanks and appreciation.

Last but not least, I would like to express my sincere gratitude and appreciation to colleagues of FAO RoS and Rome, for their continuous support, valuable input and guidance that enabled us to timely complete this FRL submission.



Dr. Sayeda Ahmed Khalil
Coordinator, REDD+ Programme Management Unit

ACRONYMS

AD	Activity Data
A/R	Afforestation and reforestation
AGB	Above-ground biomass
ABGD	Above-ground biomass density
BGB	Below-ground biomass
BUR	Biennial Update Report
CEO	Collect Earth Online
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
GEDI	Global Ecosystem Dynamic Investigation
FAO	Food and Agriculture Organization of United Nation
FNC	Forests National Corporation
FREL	Forest Reference Emission Level
FRL	Forest Reference Level
GDP	Gross domestic product
GHGs	Green House Gases
GLCN	Global land cover network
Ha	Hectare
HCENR	Higher Council for Environment and Natural Resources
NDC	National Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
LULUCF	Land use land use change and forestry
NDCs	National determined contribution
NFI	National Forest Inventory
NFMs	National Forest Monitoring System
NWFP	Non woody forest products
REDD+	Reducing Emissions from Deforestation and forest Degradation; and the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks
RoS	The Republic of Sudan Remote Sensing and Seismology Authority
RSSA	
SLC	Scan Lune Corrector
SNC	Second National Communication
SU	Sampling Unit
$t.CO_2$	Tonnes of Carbon Dioxide
TNC	Third National Communication
UNFCCC	United Nations Framework Convention on Climate Change

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUMMARY

This document presents Republic of Sudan's (RoS) National Forest Reference Level (FRL), which is submitted for the technical assessment by the UNFCCC. The reference level includes two REDD+ activities of Deforestation and Enhancement of Forest Carbon Stock. The values of the FRL are disaggregated by the 18 States of RoS. The overall average annual change in carbon stock due to deforestation is estimated at 6,932,496 tonne CO_2 /Year, over the reference period (2012-2021). The overall average annual CO_2 removals is estimated at – 2,108,584 tonne CO_2/Year due to Afforestation and Reforestation activities implemented over the reference period (2012-2021). Table 1, below provides summary description of this FRL submission and its consistency with the relevant UNFCCC guidance and summarizes the decisions made by the government of RoS in relation to the scale and the scope of FRL. This national FRL represents forest conditions in the dry lands of Sub Sahara Africa.

Table 1: Republic of Sudan's (RoS) FRL compliance with the relevant UNFCCC decisions

UNFCCC reference	Description	National FRL (2024)
Decision 12/CP.17 Paragraph II.10	Stepwise approach	National Scale disaggregated by States Builds on lessons learnt, data, methods and capacity developed by the FRL 2020 Reference historical period is 2012-2021
Decision 12/CP.17 Annex, paragraph (c)	Pools and gases	Pools: Aboveground, below ground biomass and standing deadwood Gases: CO_2
Decision 12/CP.17 Annex, paragraph (c)	REDD Activities	Reducing emissions from deforestation, this activity covers all forestland in RoS Enhancement of forest carbon stocks, covers all potential lands available for afforestation and reforestation in RoS RoS has assessed degradation areas but does not have data to estimate the associated emission factors
Decision 12/CP.17 Annex, paragraph (d)	Forest definition and consistency with GHG inventories	Forest means an area of land spanning at least a minimum area of 0.4 ha with trees that have attained, or have the potential to attain at least 2 m. in height and a minimum tree canopy cover of 10%. It includes wind-breaks and/or shelter-belts with a minimum of 20 m. in width.

		The same definition used in GHGs inventory of the Third National Communication
Decision 12/CP.17 Annex	Guidelines and Methodologies	IPCC 2006 Guidelines for national GHGs inventories and data 19R IPCC guidelines The same methodology used in GHGs inventory of the Third National Communication
Decision 12/CP.17, Paragraph II.9	Information on rationale, national circumstances and their consideration in the national FRLs	Description of national circumstances provided No adjustment is needed, The reference period is considered representatives of the current trend and capturing key milestone in national circumstances affecting forest resources in the country

1. INTRODUCTION

Republic of Sudan (RoS) is submitting this national Forest Reference Level (FRL) in response to the invitation of the Conference of Parties to the UNFCCC for developing countries to develop and submit, on a voluntary basis, FREL/FRL, for consideration by the UNFCCC. Following the stepwise approach, stipulated in decision 12/CP.17, para II.10, RoS prepared this National scale Forest Reference Level (FRL), building on the experiences, capacities, data and resources developed during the preparation of its subnational FRL (2020) as well as the feedback received through the UNFCCC technical assessment. This submission is intended for technical assessment in the context of results-based payments for reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries (REDD+) under UNFCCC (Para13 decision 12/CP.16 and para 71(b) decision 1/CP.16).

The objective of preparing the national Forest Reference Level (FRL) is to support achieving the overall objectives of the national forest programme and enhancing the contribution of the forest resources to global climate change mitigation in the context of sustainable development. This is to be achieved through enabling effective implementation of the national REDD+ Strategy (NRS) and national determined contribution (NDC) under the Paris Agreement. In its NDC (2021) RoS plans to implement low carbon development interventions in three sectors - energy, forestry and waste. The measures envisioned to achieve GHG emission reductions are consistent with RoS's national development priorities, objectives and circumstances. These measures include implementation of the National REDD+ Strategy including restoration and sustainable management of degraded forest reserve and the Gum Arabic belt; Afforestation and restoration of degraded lands including 10% of rainfed and 5% of irrigated areas of the agriculture land; Restoration/conservation of mangrove forests along Red Sea coast.

Located in North Eastern Africa, the RoS is bound by Egypt, The Red Sea, Eretria, Ethiopia, Republic of South RoS (RSS), Central African Republic, Chad and Libya, with an estimated total of 1.882 million km2 (Figure1). It lies between latitudes 100 and 220 N and longitudes 220 to 380 E. The highest point in the country is Jebel Marra; 3,024 meters above sea level (m.a.s.l.) and the lowest is the Red Sea. The most salient geographical features are the Nubian and Bayuda Deserts in the north, the Nile Valley, Jebel Marra, Nuba, and Ingessena & Red Sea Hills. The Blue Nile and White Nile Rivers originates in the Ethiopian Highlands and the Equatorial Lakes, respectively. The two rivers unite at Khartoum and form the River Nile that runs north to the Mediterranean Sea. Administratively RoS is divided in 18 State, see map in figure (1) below:

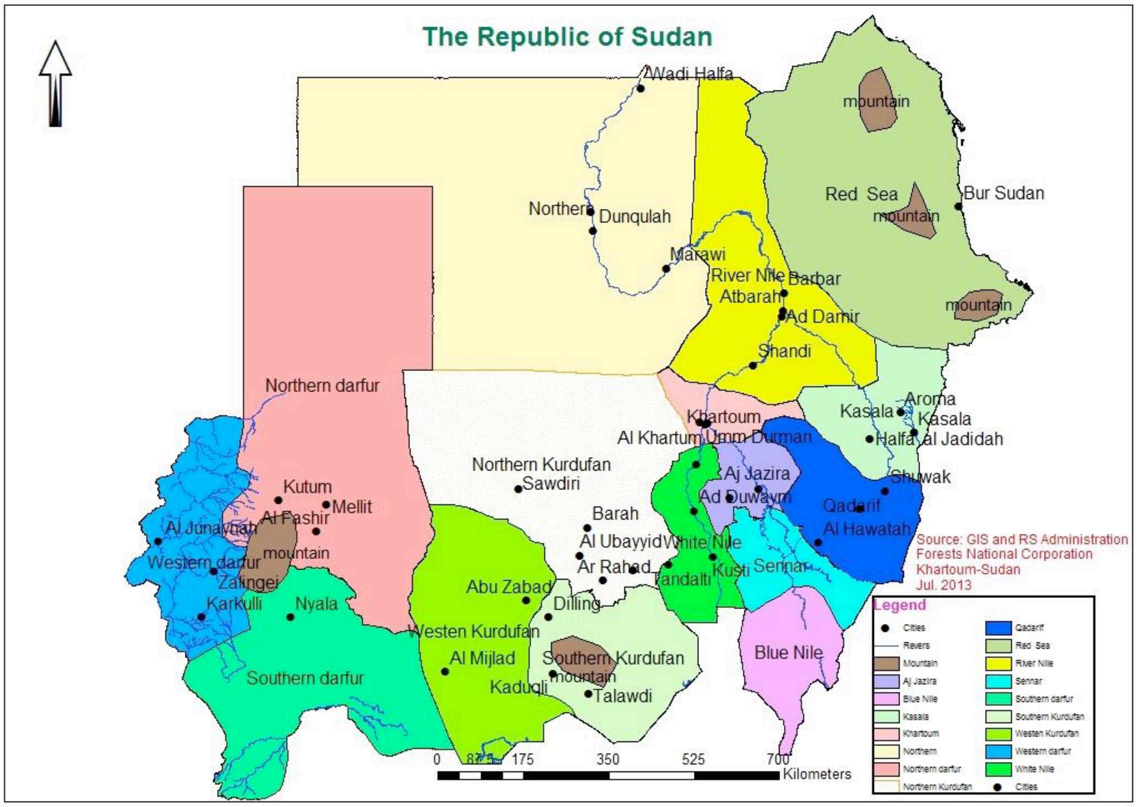


Figure 1: Republic of Sudan Map

The ecological zones of RoS extend over a wide range from the desert in the extreme north to the high rainfall savannah in the south. The country is ecologically divided into five vegetation zones following the rainfall patterns from North to South:

1. Desert: (0-75 mm of precipitation),
2. Semi-desert: (75-300 mm),
3. Low rainfall savannah on clay and sand: (300- 800 mm),
4. High rainfall savannah (800-1500 mm),
5. Mountain Vegetation: (300-1000 mm).

The country is rich in biodiversity with diverse environmental systems making it endowed with flora and fauna which are being subjected to a number of threats as a result of natural factors and human activities. According to the Land Cover Atlas of RoS, FAO (2012), Forests together with Rangeland represent 35.6% of the total country area. Forests play an important social, economic and environmental role by the goods and services they provide to support people's livelihoods. Approximately 63% of the population is rural and considered forest dependent essentially for fuelwood as main source of energy and round timber as building material. In addition to wood products, the rural population uses the forest extensively for grazing, as source of bush meat (wildlife hunting) and for food in the form of tree leaves, fruits, honey and tubers. They also use tree shade for their social functions and other recreational purposes, (FOSA, 2001). Many other non-wood forest products are collected from forests for domestic as well for commercial purposes, among these, RoS is the leader country in gum Arabic production, other incenses, tannin, etc. Forest based small industries constitute a main pillar to the national economy as well as to local economies, and provide 15% of job opportunities in the country. In addition, more than five million farmers earn their living depending on Gum Arabic production. Forests contribute 30% of the fodder requirements of the national animal herd and this contribution can reach 70% in extremely dry years.

However, deforestation remains key thread to forest resources, according to the report on Drivers of Deforestation and Forest Degradation (DoDD) (2018), deforestation has caused RoS's forest cover to decline from 76.4 million hectares (ha) in 1990 to 70.49 million ha in 2000 and 69.95 million ha in 2010 (30.5% to 28.1% and 27.9% of the country total area, respectively (FRA, 2010). RoS Cover Map report (2020) estimates forest area at 22.8 million hectares, about 12% of the total country area. The significant reduction estimated in the Land Cover Map report is also attributed to the cessation of Sudan in 2011 into two States, the Republic of Sudan (RoS) and South Sudan, where more than half of the forest area fall in South Sudan. The estimation of the Land Cover Map (2020) is based on the new forest definition, mentioned in section 2 below, which reduces the dimensions of the area, highest and crown cover.

The conversion of the forests to agriculture remains the key driver of deforestation in the country, the DoDD (2018), estimated that agriculture expansion causes 42.1%. Agriculture expansion on forestland is caused by declining productivity of cropland, poor cultivation practices and population growth (2.8% per year in 2020). Over drivers, unsustainable extraction of fuelwood and charcoal for energy causes 19.8% and animal overgrazing causes 15.1% of the deforestation and the forest degradation in RoS.

RoS is one of the most vulnerable countries to climate change and hence accords high priority to the international cooperation to fighting climate change and avoiding its devastating consequences. REDD+ is among the top priority programmes in RoS to participate in the global mitigation efforts and to build resilience in its land sector, which host about 70% of the population. RoS is committed to the objectives of the global REDD+ programme and is working towards integrating these into its national forest programme and management practices. The National REDD+ Strategy (NRS) (2021) vision is to achieve sustainable management for a green economy while contributing to RoS's prosperity, livelihoods, and wellbeing. This is to be achieved through building synergies with, and contribute effectively to, the National Development Strategy, which aims towards achieving a green prosperous country by 2030, while maximizing carbon and non-carbon benefits through improved sustainable natural resources management. The Strategy defines the general direction that the RoS will take to achieve the vision of the REDD+ programme. The NRS outlines five broad strategic options (Table 2) to be implemented through a set of policies (PAMs) and actions that collectively address the direct and indirect drivers of forest deforestation and degradation.

Table 2: The Strategic Options and PAMs of the NRS

	STRATEGY OPTION
STRATEGY OPTION 1: INTEGRATED FOREST LANDSCAPE MANAGEMENT	
PAM 1	Strengthen sectoral policies, financing, and institutional capacity
PAM 2	Strategic landscape management, restoration and emission reductions
PAM 3	Support for forestry research and development
STRATEGY OPTION 2: CLIMATE SMART AGRICULTURE AND RANGELAND MANAGEMENT	
PAM 4	Improving the adaptive and climate mitigation capacity of the agriculture sector
PAM 5	Promoting sustainable livestock and rangeland management
STRATEGY OPTION 3: INTEGRATED LAND USE PLANNING	
PAM 6	Harmonizing land use planning, investment policies, and legislation
PAM 7	Sustainable land management stewardship through land tenure security
STRATEGY OPTION 4: SUSTAINABLE ENERGY SUPPLY AND USE	
PAM 8	Increasing access to efficient and sustainable household energy
PAM 9	Promoting a sustainable biomass-based energy value chain
STRATEGY OPTION 5: PROMOTING PARTICIPATION IN CLIMATE CHANGE RESPONSES	
PAM 10	Advance the participation of youth and women

2. FOREST DEFINITION

RoS's defines forest as an area of land spanning at least a minimum area of 0.4 ha with trees that have attained, or have the potential to attain at least 2 m in height and a minimum tree canopy cover of 10%. It includes wind-breaks and/or shelter-belts with a minimum of 20 m in width". This forest definition has been developed after cessation of RoS in 2011 into two states of RoS and South RoS. The rationale behind the new definition is to enhance the protection and production functions of the remaining forest resources. The new definition also responds to climate change requirement for forest definitions and enables realization of the role the forest resources envisioned to play in meeting RoS's obligations under the UNFCCC and Paris Agreement.

The new forest definition was also used in the last national forest inventory (NFI Report 2021) and in the GHG inventory prepared for RoS's Third National Communication (TNC) to the UNFCCC and RoS's first Biennial Update Report (BUR).

The RoS does not have official definitions for the five REDD+ activities. However, for the purpose of this submission it is agreed that, within the circumstances of RoS, deforestation occurs as a result of conversion of forestland to other land use, mainly to cropland. Afforestation occurs on land that was not forest before, such as cropland, abandoned, degraded lands, etc, while reforestation occurs on bare lands in degraded forests areas that was cleared of their tree cover through human activities, mainly cultivation, and the cleared areas cannot regenerate naturally without human intervention, because of various reasons including the continuation of the same activities that causes their clearance.

3. CONSISTECY WITH GHGs INVENTORY REPORTING

This FRL submission is consistent with the GHGs inventory reports prepared for RoS's Third National Communication (TNC) and first Biennial Update Report (BUR). In particular:

- TNC, BUR and this FRL submission apply the same IPCC 2006 guidelines
- Some of the national data sources (FNC and research) of emission/removal factors and other parameters are also used in this FRL submission and TNC/BUR.
- NFI (2021) data has been used by the FRL submission and the first BUR submission
- The same Forest definition has been used in the FRL submission and in TNC/BUR submission

The publication of the TNC and first BUR was planned in 2021, however, because of number of internal reasons including the current unrest situation this has been delayed.

4. SCALE OF THE FRL

The conclusions of the UNFCCC technical assessment on RoS subnational FRL 2020, identified one technical area for future improvement relevant to the scale of RoS's next FRL, which is the need to consider inclusion of other forest biomes as part of the efforts to construct a national FREL or FRL;

Accordingly, RoS decided to prepared this FRL as a national scale level covering all forestland and all land areas potentially available for enhancement of forest carbon stock in RoS. The estimation of emission associated with deforestation REDD activity covers all the areas of forestland in the country meeting the national forest definition. The estimation of the removals associated with the REDD activity of enhancement of forest carbon stock covers all potential land available Afforestation and Reforestation (A/R) in the country.

The study on activity data conducted for this submission estimates the area of Forestland in RoS at 18,430,970 ha, about 10% of the total land area. Almost 98% of the forestlands are located in the southern part of the country, within strata 3 and 4, the remaining about 1% are mostly Riverine forests located in strata 5 which is the area along the River Nile and its tributaries intersecting all other strata from south to north. Strat 1 and 2 represent the desert and semi-desert part see table 3 below. Also see the maps figure 2 in section 6.1 below show the distribution and location of the forestland in the different stratum:

The national FRL 0f RoS will be disaggregated by States (subnational administrative units), consistent with the Forest National Corporation institutional arrangements, REDD management arrangements and the NFMS/MRV system. This will facilitate implementation of the national REDD+ strategy, emission reduction programmes/projects and the engagement of stakeholders at subnational levels. The deforestation FREL covers all the States with forest loss (about 13 States). White the enhancement FRL covers areas in all the states, where there is potential for implementing afforestation and reforestation activities.

Table 3: Forest land per stratum

Stratum	Forests
Strata I (Desert)	0
Strata II (semi-desert ecosystems)	316,953
Strata III (Low rainfall woodland Savannah)	1,415,577
Strata IV (semi-arid, dry sub-humid and humid aridity zones)	16,541,001
Strata V (rivers and streams)	157,439
Total	18,430,970

4.1. The Historical Reference Period (RP):

The UNFCCC requires historical data to be taken into account in the construction of FREL/FRLs, however, it does not prescribe the length or the period that countries should use in the analysis of historical data. The historical period should provide for a realistic and robust benchmark to assess the mitigation performance of REDD+ activities. Ideally, it should represent the development, dynamics and current trends in historical emissions. Number of REDD+ supporting and funding agency prefers 10 years reference period representing the most recent trend in the development of the forest sector.

In selecting the RP for this national FRL, RoS considered selecting a timeframe that encompasses key historical events, drivers and policies resulting in major impacts on the development of its forest sector. In this regards the secession of South Sudan in 9 July 2011 is considered the most important historical event affected forest resources. It was roughly estimated that about 60% of forestland and one third of the population become part of the state of South Sudan. As a result, 60% of the Republic of Sudan (RoS) population are currently dependent on the remining forest resources. Given the fact that the population of the RoS is highly dependent on biomass energy (more 60% of the energy used), agriculture and livestock husbandry (more than 70% of the population). This situation has led to high pressure on the remaining forest resources and increases the rates of deforestation and forest degradation.

The national REDD+ Readiness Programme has established NFMs/MRV arrangements, a sub-national FRL, a Safeguards information system and adopted a National REDD+ Strategy during the period 2017-2021. All these are also important milestones for REDD+ implementation and for consideration in reference period determination.

The current forest Act issued 2002, is also an important development in the forest management and protection, it provides more consideration towards an integrated management approach including other natural resources such as rangelands. The Forest Act has provisions on allocation of 10% of the rainfed and 5% of the irrigated agricultural schemes to forestry and tree planting, aiming towards reversing deforestation, addressing land degradation and the poor productivity of cropland area, particularly in the mechanized rainfed areas which were originally forested area cleared of their tree cover and were subjected to mal-cultivation practices and are currently mostly degraded or degrading lands.

Taking into account all above-mentioned considerations, the RoS decided to apply and a reference period covering the timeframe of 2012 – 2021, which is representative of the current trends in the forest sector, it takes into consideration the important historical development mentioned above as well as allowing the possibility to use recent data and methods becoming available since the last sub-national FRL submission.

5. SCOPE OF THE FRL

Following the UNFCCC stepwise approach, decision 12/CP.17, para II.10, the scope of RoS's subnational FRL 2020 has included the most significant REDD activities, pools and gases. The REDD activities of deforestation and enhancement of forest carbon stock, the above and below ground biomass carbon pools and Carbon Dioxide was the only gas included. The key limitations to expand this scope to cover other activities, pools and gases were lack of good quality data, resources, e.g. to assess carbon stock change due to forest degradation and the significance of the contribution of other pools (e.g. deadwood, soil, litter). The conclusions from the UNFCCC technical assessment found the omission of some activities, pools and gases in 2020 FRL justifiable, however, identified three technical areas of improvement relevant to the scope of the national FRL, these include:

- Inclusion of other REDD+ activities, in particular reducing emissions from forest degradation, when new, adequate data and better information become available;
- Treatment of emissions from the deadwood, litter and soil pools
- Treatment of emissions of non-CO_2 gases (to maintain consistency with the national GHG inventory)

5.1. REDD+ Activities of the FRL:

The two REDD+ activities of reducing emissions from deforestation and enhancement of forest carbon stock, remain the most important and significant REDD+ activities in RoS. There are reliable data, information and experience for estimating them with more accuracy and therefore are included in the national FRL.

Forestland conversion to cropland remains key driver of deforestation, it is estimated that agriculture expansion causes 42.1% of forest loss. Agriculture expansion on forestland is caused by declining productivity of cropland, poor cultivation practices and population growth (2.8% per year in 2020). The DoDD (2018), made some important conclusion based on an analysis of a time series data of 63 years (1953-2016) of the cultivated area, production and productivity of the major food commodities (cereals and oilseeds). The area cultivated increased from an average of 5.6 million feddans to 41.3 million feddans during this period, indicating an increase of more than seven folds. The percentage of the area harvested decreased from an average of 90% to only 69% during the same period, implying a loss of productivity of almost 31% of the area under cultivated. The production increased during this period by about four folds from 1.5 million metric tons 6.7 million metric tons. This result indicates clearly that the country is relying on horizontal area expansion for food security.

On the other hand, RoS has a significant potential to implement the REDD activity of enhancement of forest carbon stock, due to the size of its land area and the vast forestlands cleared for agriculture production during the time since 1940s-1990s and beyond, most of these areas are left degraded or are degrading now. The potential land available for afforestation and reforestation is estimated at more than 9 million ha, including bare lands inside degraded forest areas, degraded area within the Gum Arabic belt, 5% the area of the irrigated agriculture schemes and 10% the areas of the rainfed agriculture schemes, the latter two are based on the provision in the Forest Law (2002). The estimated land area of rainfed sector does not include the traditional rainfed sector, which has the largest share of about 60% of the total rainfed area in the country. Data on the areas of the annual afforestation and reforestation activities is available in the records and annual reports of FNC HQ and its offices in the 18 states of RoS.

As stated in the 2020 FRL submission and discussed during the UNFCCC technical assessment, forest degradation is also a significant REDD activity. However, RoS lacks the required suitable emission factors to assess carbon stock change due to forest degradation. RoS does not have historical data and records from regular NFI measurements. The recent NFI (2021) report provide data based on measurements conducted during 2017-2020. However, NFI process is still being established to ensure regular measurements and updated data in future including changes of forest carbon stock over time, the effect of wood extraction and overgrazing which are key drivers of forest degradation. Also, RoS lacks quality and regularly updated data on wood consumption, demand and supply, particularly of wood for energy, which is also important data for assessing forest degradation. Forest degradation will eventually be included following the stepwise manner, when reliable data become available.

The work conducted to develop the activity data (see table 10) for estimating emissions from deforestation has also provided us with estimates of the areas of forest degradation in the different states. Table 4 below provide approximate estimation of the emission associated with forest degradation in RoS. These estimates are developed using values of emission factors equal to 30% of the forest carbon stock (AGB, BGB and standing DW) in the respective States.

Table 4: Approximate Estimates of Average Annual Emissions of Forest Degradation (2012-2021), t.CO2/Year

States	Forest degradation Area	Average net annual emissions	
	ha/year	t.CO_2/Year	CI 90%
Blue Nile	5,485	54548	75%
Central Darfour	2,219	21976	119%
Eastern Darfour	7,203	83375	62%
Gadarif	2,157	6158	130%
Kassala	303	277	222%
Northern Darfour	363	639	173%
Sinnar	3,970	43647	73%
Southern Darfour	15,161	220416	44%
Southern Kordofan	17,386	182222	35%
Western Darfour	1,472	5814	149%
Western Kordofan	17,771	195651	38%
White Nile	666	500	150%
Grand Total	**74,156**	**815,223**	**20%**

Regarding the inclusion of the other REDD+ activities of sustainable management of forests and conservation of forest carbon stock. Currently there is no data to assess emissions/removals associated with these activities in RoS.

5.2. Carbon pools:

The UNFCCC decision 12/CP.17, Annex paragraph C, requires significant carbon pools to be included in the FREL/FRLs, otherwise reasons of their omission should be provided. In its 2020 FRL submission, RoS included above and below ground biomass carbon pools and provided the reasons for the omission of other pools of deadwood, litter and soils. The UNFCCC TA accepted the reasoning of RoS, considered the excluded pools are likely to be insignificant in the context of 2020 subnational FRL. However, it identified treatment of emissions particularly from soil, deadwood pools and fires as areas for technical improvement in future FRL submissions.

The NFI (2021) provides good quality data on above-ground and below-ground biomass carbon stock, disaggregated by stratum, land use and states (administrative units). These two pools are also considered the most significant in all national GHG inventories reported in national communications submitted by RoS and therefore, are included in this national FREL/FRL.

The estimation of the amount of dead wood in RoS is difficult, because significant amount of deadwood is collected directly by local communities living in the proximity of the forests to meet their immediate energy demands. Biomass energy is the main source for rural communities and for a significant portion of the urban population, it constitutes more than 60% of the energy balance in RoS. The Forest Product Demand Study (1995), estimated the amount of wood fuel directly collected at about 72% of total fuelwood used in RoS. This is amount is mostly deadwood (fallen and stumps) and is not captured in available records and is consumed in the same year of its collection. Resources permitting, FNC needs to update the forest products demand survey of 1995, including household surveys, to develop quality estimates of the amount of wood directly collected from the forests.

RoS does not have repeated measurements NFI data on deadwood. The NFI (2021) provides the first data on the volume of dead wood remaining in the forests. In this submission RoS includes only standing deadwood in the estimation of emission associated with deforestation. According to the NFI field experts the data collected on standing deadwood is more reliable compared to the data on fallen and stumps deadwood.

The NFI (2021) does not provide information on soil, generally there is no good quality data on soil available in RoS, and this is also recognized in the GHGs inventory reported of RoS's national communications to date. Table 5 below summarize the carbon pools included in this submission.

Table 5: The carbon pools included and omitted in the national FRL

Pools	Inclusion in FRL	Justification
Aboveground biomass	Included	Significant, good quality NFI 2021 data
Belowground biomass	Included	Significant, good quality NFI 2021 data
Deadwood	Partially included	Standing deadwood, NFI 2021 data
litter	Not included	Not significant in drylands, Lack of data
Soil organic carbon	Not included	Lack of data

5.3. Greenhouse Gases:

In the Forest Reference Level (FRL) submitted in 2020, Sudan focused exclusively on carbon dioxide (CO2) emissions. The UNFCCC Technical Analysis (TA) identified the need to address non-carbon dioxide (non-CO2) gases (to maintain consistency with the national GHG inventory) as an area for future improvement. CO_2 remain the most significant gas in GHG inventory conducted in RoS (INC 2003, SNC 2013 and TNC yet to be published). The data and country specific parameters required to obtain good quality estimates of non-CO_2 are currently not available, RoS continue to use more default parameters, emission and conversion factors in most of the categories reported in its LULUCF inventory.

6. ACTIVITY DATA FOR DEFORESTATION

In the context of forest monitoring, Activity Data (AD) refers to information on human or natural actions that result in changes to forest cover and land use. Key activities tracked under AD include deforestation, afforestation, reforestation, and forest degradation. AD can be extracted from different sources, though for the current submission RoS relies preliminary on remote sensing information to track deforestation for an envisaged monitoring period of 2012-2021 at national scale. Whereas information on forest enhancement, including afforestation and reforestation, is mainly coming from national statistics records from Forest National Corporation (FNC). The current reporting is using an updated methodology for the second Forest Reference Level (FRL) submission considering the previous Technical Assessment (TA) team's review.

The stratified area estimate approach is an established method for assessing unbiased area estimates of land cover, land use and land use change, leveraging the statistical advantages of stratification to improve the precision around respective area estimates (Olofsson et al. 2014, FAO 2016).

For this FRL submission, two separate stratifications have been overlaid. The first stratification is based on ecological zones divide the forest landscape into distinct strata based on key variables such as forest type, land-use history, or ecological characteristics. This stratification has been employed in the NFI, and samples have been allocated to each stratum systematically, but with different intensities. It is further described in 6.1.1.

Further intensification on the above-mentioned stratified systematic grid has been added using a second stratification with low, medium and high probability of forest and forest change. This stratification is obtained through a forest change assessment based on satellite remote sensing. Subsequent sample allocation has been done by using a statistically optimized approach and samples have been placed in a random fashion. This second sampling strategy aimed at enhancing the precision specifically around the forest change area estimate and is further described in 6.1.2. The derivation of the stratification layer is outlined under 6.2.

The combined sampling design can be contextualized as a stratified random sampling and accordingly estimators have been employed as described in section 6.5.

6.1. Sampling Design

6.1.1 Systematic NFI grid based on permanent stratification

RoS implemented a systematic grid in 2017 as part of its National Forest Inventory (NFI) project to collect the field information at the national scale. Given the country's diverse ecosystems, a geospatial analysis was conducted to categorize RoS into distinct zones. This classification was based on available geospatial layers, including ecological zones, global tree cover, and land cover data. The resulting layer, referred as the strata boundaries, formed the foundation for generating the NFI grid. Table 6 provides a detailed description of the five strata.

Table 6: Description of the Strata, along with total area covered by each stratum

Stratum	Description	Area (ha)	Area (%)
I	The stratum that mostly comprised Deserts	67,327,512	36
II	The stratum characterized by semi-desert ecosystems (e.g. few Acacia trees and thorny bushes and zerophytes)	38,802,725	21
III	The stratum indicated as 'Low rainfall woodland Savannah' by Harrison and Jackson (1958)	35,695,771	19
IV	This stratum includes semi-arid, dry sub-humid, humid aridity zones. Forest and Woodland vegetation is mostly found here.	42,743,777	23
V	This stratum includes rivers and streams. It is probably the most heterogeneous since it is the stratum where human activities are dominated, and patches of vegetation (natural and not) found as riverine vegetation. This layer crosses all the latitudes of the country.	2,438,969	1

Recognizing the ecological diversity across the country, different sampling intensities were applied based on the specific characteristics of each zone defined in Table 5. For instance, the arid northern region, dominated by desert landscapes, was assigned a less dense grid with a higher expansion factor. In contrast, the forest-rich southern regions, characterized by dense vegetation, were assigned with a denser sampling grid (Figure 2). The distribution of sample intensities and field-collected samples for the NFI cycle (2017–2020) is summarized in Table 7.

Table 7: NFI Sampling Design: Distribution of Sample by Stratum and total filed visited samples during NFI cycle 2017 -2020

Stratum No.	Total No. of sample units	Total sample collected in Field	Spacing of sample unit grid
Strata-I	107	-	80 * 80 Km^2
Strata-II	123	20	80 * 40 Km^2
Strata-III	431	159	40 * 20 Km^2
Strata-IV	1,065	577	20 * 20 Km^2
Strata-V	29	28	Random
Total	**1,755**	**784**	

The systematic grid is used as a basis for the AD collection as it covers the full country. It further facilitates consistent and repeatable data collection in the future, making it suitable for generating consistent long-term land use and land cover (LULC) statistics, as it is not subject to sampling variability. The activity data was collected across the entire grid population of 1,755 sampling units, though field data from NFI cycle is only available at 784 sampling units.

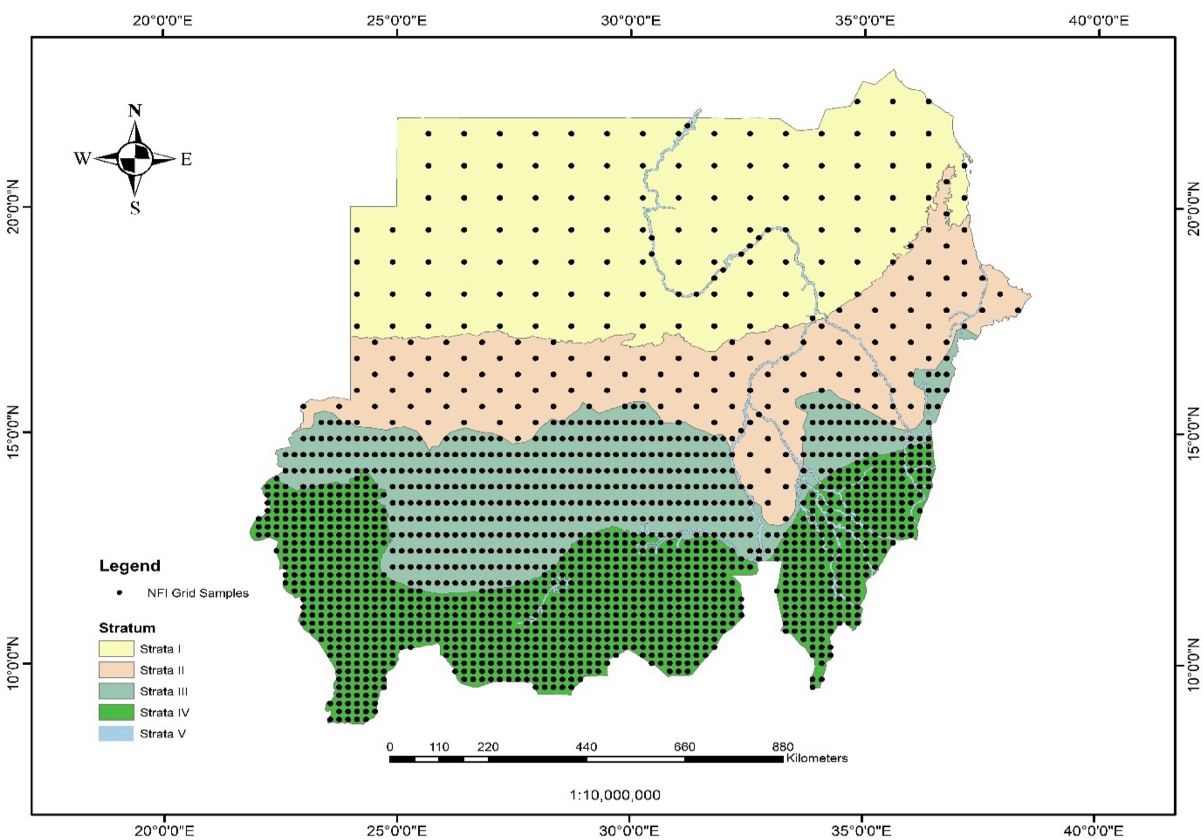


Figure 2: Geographic distribution of sample intensities over each stratum

6.1.2 Intensification of the sampling grid

Stratum III and IV were subject to sampling intensification, as those are the ones containing forest. The intensification process was based on a second stratification that was derived through remote sensing based change analysis over the reference period using SEPAL, a cloud computing platform developed by FAO's forestry team. The approach follows a modified map subtraction workflow between two Forest/Non-Forest maps at the beginning and the end of the reference period. The important difference to a classical map subtraction is that it is not using the categorical output of the classifier, but rather the class probability of the pixels being forests. Subtracting those forest probabilities results in a more nuanced distinction that can be referred to as likelihood of being forest change. This layer of change likelihood is then used in a statistically optimized procedure to divide the area into relevant change strata and allocate an optimal number of samples randomly. The process to generate the stratification can be broken down into following steps:

1. Training data collection
2. Provision of satellite image composites
3. Creation of Forest non-forest (FNF) probability maps at time 1 and 2
4. Change probability layer (CP) through probability map subtraction
5. Unsupervised stratification of change probability layer
6. Optimal sample allocation

6.1.2.1 Training data collection

The training data was received from a prior land use and land cover mapping exercise conducted in 2020 by the Geospatial Department of the FAO. The training data was collected using eight Land Use Land Cover (LULC) classes namely: forest, bare rocks and soils, cropland, herbaceous, shifting cultivation, shrubland, urban areas, and water bodies. For this purpose, the data was remapped into two categories: forest and non-forest classes (Table 8). A total of 4,966 samples were collected in 2020 using Collect Earth Online (CEO) at a spatial scale of 100 meters using proportional allocation. Reclassification was conducted using a majority rule, where samples with greater than fifty percent forest are considered forest, and the remaining samples were assigned as non-forest. The training data was consistently applied across both years classification.

Table 8: Categorization of training data into Forest and non-Forest class

Sr. No.	LC class	Re-Categorization
1	Forest	Forest
2	Bare Rocks and Soil	non-Forest
3	Cropland	
4	Herbaceous	
5	Shifting Cultivation	
6	Shrubland	
7	Urban	
8	Water Bodies	

6.2.2. Provision of satellite image composites

Wall-to-wall image mosaics generated from satellite data serve as a predictive input to the classification procedure alongside the labelled training data. In order to capitalize on the latest technological advances, RoS used a combination of data originating from optical and radar sensors. The selection was based on the availability of the data for the envisaged monitoring period and geographic coverage. For this analysis data from the Landsat missions, the Planet NICFI programme and the ALOS Kyoto & Carbon initiative was used.

Landsat Composite: Landsat composites for the year 2011 and 2023 were created using SEPAL's Optical mosaic recipe. First, an annual composite for the year 2011 was generated using satellite data from Landsat 4-5. Missing areas of incomplete coverage were filled in by data from the preceding years. Similarly, Time-2 composites were generated for the year 2023 and 2024 using step by step guide available at SEPAL documentation page. The year 2024 is introduced as a buffer year, the idea behind temporal buffer is to avoid potential omission of changes that might happen at the start or end of year. Such changes would not be captured in the subsequent change analysis when using the best pixel composite, since pixel information in these mosaics could come from any point in time within selected dates. The buffer year is defined here as start of envisaged monitoring period and minus one year (2010 & 2011) and end of monitoring period and plus one year (2023 & 2024). For 2011 it was not possible to create two separate mosaics for year 2011 and 2010 because of limited data availability therefore, a combined composite for the years 2009-2011 was created.

Planet Composite: The annual composites are generated by aggregating data from monthly basemaps of Planet NICFI. The mosaics are extracted using Planet mosaic recipe in SEPAL for the year 2023 and 2024. A step-by-step process is available at the link.

ALOS Mosaic: L-Band Radar data for the envisaged monitoring period was available through ALOS Kyoto and Carbon (ALOS K&C) initiative, which provides global 25m PALSAR/PALSAR-2 mosaics on an annual basis. Backscatter data from long wavelength radar systems provides complementary information on the land cover. As the backscatter over vegetated areas is coming from woody elements, it is less dependent on the presence of leaves and can therefore detect seasonal dry forests outside their leave-on period.

The ALOS K & C mosaic were created using the following Google Earth engine (GEE) script. This code creates a mosaic over RoS for the year 2010 and 2023 separately. The workflow defines the area of interest (boundary), retrieved the composite for specified year, and applies noise reduction and calibration. The key metrics like texture (contrast, entropy) and polarization ratios (HH/HV) are computed to analyse surface properties. The processed image is visualized and exported as an asset to GEE. The script is very automatic and only required two changes namely AOI and year.

Data Retrieved: All mosaics were exported to GEE as an asset at 30-meter scale regardless of original resolution. This was done to maintain the consistency among datasets used for activity data (AD). It's important to mention that stratification layer leverage the data from buffer year, but reference data collection was strictly confined to 2011-2023.

6.2.3. Forest Non-Forest (FNF) Probability Maps

Forest/Non-Forest probability maps were produced using supervised classification in SEPAL, where the annual composites from the relevant years were combined with the training data to generate FNF probability maps for each of the respective years. The classification was run separately for both 2011 and 2023 using the stable set of training samples. For the FNF probability map 2011 input data from ALOS K & C and Landsat was used whereas for 2023 ALOS K & C , Landsat and Planet composite from respective and buffer year were used for classification. Table 9 is providing detailed description of input images along with band combinations and indices used for classification, All datasets are downloaded as GEE assets and asset id are provided in Annex-5. A random forest classifier was used which was calibrated using input training data and annual composites from respective years. One of the important parameters using random forest classifier is the number of trees used in the underlying bootstrapping. By default, this is set to 25 and was increased to 1000. Instead of the categorical output, the class probability layer of forest is extracted with values ranging from 0-100. The resulting classification was exported to GEE. The details workflow of this analysis is given in Figure 3 of the document.

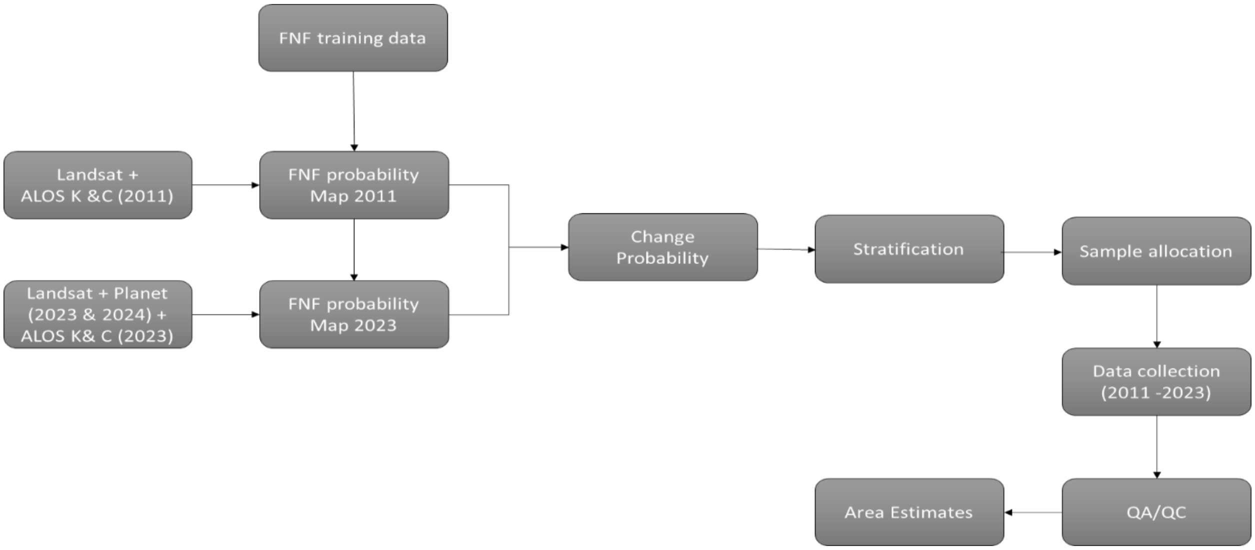


Figure 3: Showing workflow of the activity data

6.2.3.1 Post-Processing

The coverage of the ALOS mosaics was incomplete due to small gaps. To fill the gaps, an additional forest probability layer was generated using only the optical data, following the same process as explained above. Gaps in the multi-sensor probability layers were then filled in with the probability values of the classification using only optical data.

Table 9: Depicting details of Optical and Radar composite used for classification along with relevant bands.

Sensor	Monitoring Time	Composite Image Sensor	Band & Index used	Composite Year
Optical	Time- 1	Landsat 4-5 composite	Red, NIR, SWIR-1, SWIR-2, SAVI, NDFI	2009 -2010[1]
Radar		ALOS K & C Timescan	HH, HV, HHHV_ratio	2010
Optical	Time -2	Landsat 8	Red, NIR, SWIR-1, SWIR-2, SAVI, NDFI	2023
		Landsat 8		2024
		Planet NICFI Basemap	Blue, Green, Red, NIR	2023
		Planet NICFI Basemap		2024
Radar		ALOS K & C Timescan	HH, HV, HHHV_ratio	2023

[1] Because of insufficient image availability composite image period was extended to 2009-2010

6.2.4. Change probability Layer

After generating the FNF probability layers for the start and end of the envisaged monitoring period, the change probability layer was generated by subtracting the FNF probability of 2011 with the one from 2023. As an increase in forest probability would lead to negative values, the operation is using the absolute values of the difference, thus leading to the change probability layer with values ranging from 0 to 100 as follows:

Change Probability layer = Abs (FNF probability 2011 – FNF probability Map 2023) *Equation- 1*

6.2.4.1. Inclusive Forest Mask

The northern part of the RoS is largely desert, with no indication of forest, as confirmed by the initial interpretation using systematic grid sampling. Therefore, prior to stratification, a potential non-forest area was masked out by applying a threshold value of five. This threshold was determined through visual interpretation of Forest and Non-Forest (FNF) probability maps for both 2011 and 2023. The rationale for setting this threshold was to generate an inclusive forest mask that captures the potential forest extent, ensuring that no forest areas or subsequent changes were overlooked.

6.2.5. Stratification of change probability

KMeans is a clustering algorithm that groups data points based on statistical assumptions, whereby it minimizes the intra-cluster variance while maximizing inter-cluster differences. Therefore, this method is effective in stratifying skewed populations (Kozak (2011). It has been used on top of the masked change probability from the previous step, grouping the data into 3 strata.

6.2.6. Sample Allocation

Sample allocation was based on the optimal sample allocation scheme following Neyman (Neyman, 1934, Cochran, 1977). This method uses the stratum size and the underlying variability in change to calculate optimal number of samples to be allocated in each stratum. Strata with larger populations or higher variability get more samples. It is calculated as follows:

$$\boldsymbol{n_h = \frac{N_h \cdot S_h}{\Sigma(N_h \cdot S_h)} . N}$$ *Equation -2*

n_h = *Number of samples allocated to stratum h*
N_h = *The size (or area) of stratum h (e.g., total count or area in hectares)*
S_h = *The standard deviation of the variable of interest (e.g., change probability) within stratum h*
$\Sigma(N_h \cdot S_h)$ = *The weighted variability across all strata (used to normalized)*
N = *Total number of samples to be collected (target sample size)*

In case of RoS, three stratums were created within a mask generated after applying a threshold whereas area outside mask was consider as fourth stratum. The sample intensification using stratification was performed only in permanent strata (NFI Stratum) three and four of the country. This decision was taken based on preliminary analysis of systematic grid which confirmed the proposition of no forest loss in strata one and two whereas strata five was skipped because most of the activities around Nile River (Strata-5) are cyclic in nature and are part of local forest management practices. Table 10 is showing sub-stratification of strata three and four.

Table 10: Sample intensification by stratum along with total area of stratum in hectares

No.	NFI Strata	Temporary Strata	Allocated Sample	Total area
1	Stratum I	Masked	107	67,674,160
2	Stratum II	Masked	123	38,985,260
3	Stratum III	Outside mask / no change	1,055	27,467,985
		Low change probability	551	6,735,925
		Medium change probability	213	1,516,955
		High Change probability	83	251,445
4	Stratum IV	Outside mask/no change	183	2,109,760
		Low change probability	2,130	23,631,535
		Medium change probability	1,940	13,277,357
		High Change probability	1,142	4,142,388
5	Stratum V	Masked	31	2,440,303
Total Sample			**7,558**	**188,233,073**

6.3. Data Collection

A customised response design was prepared for data collection (Figure 4), which was later translated into a Collect Earth (CE) survey for data collection. Collect Earth is an open-source tool developed by the FAO under the Open Foris initiative, designed to simplify land use, forestry, and environmental assessments through satellite imagery and geospatial data. It is integrated with platforms like Google Earth and Google Earth Engine, which allow users to monitor deforestation, afforestation, and land-use changes with ease. It has been widely used for reference and monitoring data collection by various countries. The response design used for data collection is attached as an

Annex-8 of this document which provides definition of each LULC and changes classes along with explanatory variables.

Data was collected for the period 2011 until 2023 in a backward moving direction. First the information on Land Use Land Cover (LULC) class was collected (Figure-5, survey card one) for 2023. In case of forestland, an additional question about tree cover percentage needed to be answered. In case of a change event, information about LULC changes was collected in a second survey card. This information includes the respective year and the driver of change. A third survey card gathered general information over each sample such as satellite imagery used for decision making, and confidence on collected information along with comments.

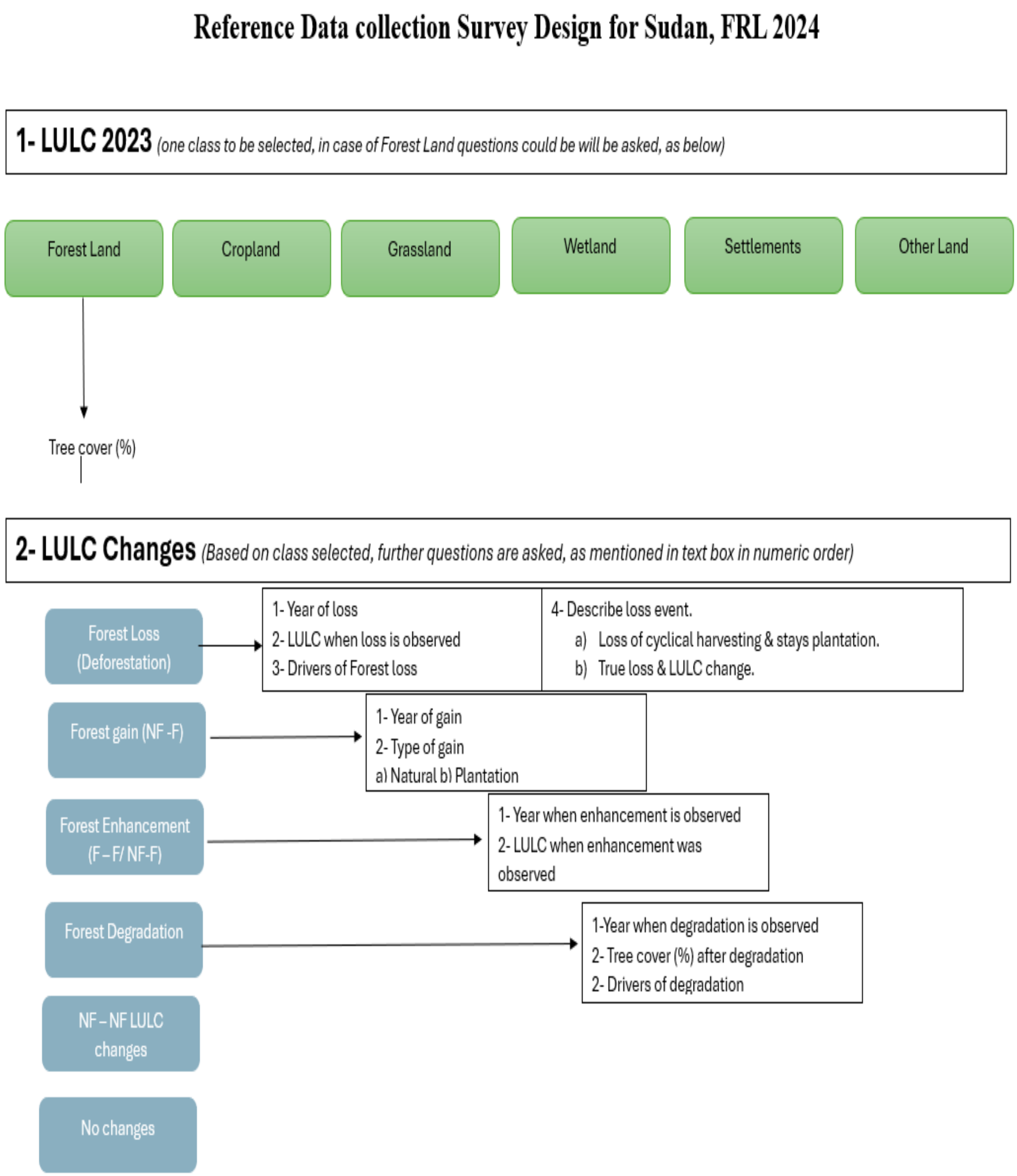


Figure 4: Customized Response Design established for Republic of Sudan for data collection

Figure 5: Collect Earth Survey Card used for activity data collection using Collect Earth software

6.4. Capacity Building

Two capacity building workshops were organized by FAO with RoS Team to develop the capacity of the team. In the first training workshop expert from FAO familiarizes the participants with collect earth software and response design to be used for data collection. After the workshop samples were equally distributed among the participants. The workshop was followed by multiple troubleshooting sessions with the team during the data collection process. After the first round of data collection an additional set of samples were generated using the stratification layer and distributed among team members, list of core Remote Sensing team is provided in Annex-9 of this document. The second training workshop conducted by FAO was designed to familiarize the team with the SEPAL platform, focused on two primary processing recipes: 1) Optical Mosaic and 2) Planet Mosaic. Following the workshop, the team was assigned the task to generate Landsat and Planet composite images for envisaged monitoring period of 2011 -2023, which were then used to produce FNF probability maps.

6.5. Results

After data collection area estimates are calculated at Strata and States levels, Strata served at permanent stratification for national forest monitoring system. Whereas forest management is mainly governed by state administration. Both level estimates are extracted from same set of samples, where information of strata and states is extracted by spatially overlaying samples over the respective shapefiles.

$$A_{ij} = \frac{n_{ij}}{n_i} \cdot A_i \qquad \textit{Equation- 3}$$

Where:

A_{ij} = *Area of class j in stratum i.*
n_{ij} = *Total number of samples of class j in stratum i.*
n_i =*Total number of samples in stratum i.*
A_i = *Total area of stratum i.*

$$SE = \sqrt{\frac{p_{ij} \cdot 1 - p_{ij}}{n_i - 1}} \cdot A_i \qquad \textit{Equation - 4}$$

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.*

The areas of each class within a stratum is calculated using equation 3, where the number of samples in each class within the relevant stratum is divided by the total number of samples in that stratum and then multiplied by the total area of the stratum. The Standard Error (SE) for a given class in a stratum is calculated using the equation 4, which is then multiplied by the Z-score (1.64) to derive the 90% confidence interval (CI) and converted to percentage. The data collected pertains to six classes: forest loss, forest degradation, forest gain, other changes, stable forest and stable non forest. Detailed description of each class is provided in the data collection sections and Annex-10 of this document. RoS reports forest loss from this analysis for the current Forest Reference Level (FRL) submission. During the reference period (2012 – 2021) the total area of deforestation observed is estimated at 2,059,749 ha, with an annual deforestation rate of 205,979 ha over this period.

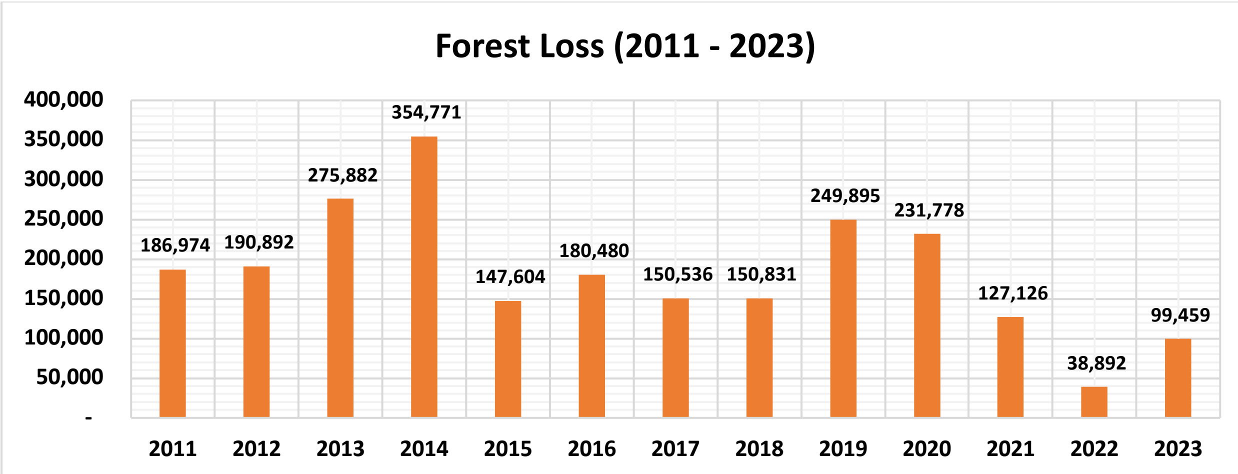


Figure 6: Annual deforestation trend from 2011-2023

Figure 6 illustrates annual deforestation rates over the reference period, does not clearly indicate a specific trend. Though, the highest deforestation rates were recorded in year 2014, followed by 2013 and 2019, while the lowest deforestation occurred in 2022. Operators often struggled to pinpoint the exact year of deforestation due to inconsistent availability of high-resolution data, particularly during the early years of the monitoring period. Consequently, the accuracy of determining the precise year of change heavily depends on the availability of high-resolution data.

6.5.2. Results by States

RoS is divided into eighteen states, with forests present only in thirteen of them, predominantly located in Strata 3, 4, and 5. According to the current analysis, the forest changes are mainly confined in strata 3 and 4 of the country, which are main forest vegetation zones. The stratum four, forest rich zone in the southern part of the country, exhibits the highest levels of deforestation, driven predominantly by agricultural expansion and other human activities. Whereas Stratum three, also shows significant changes, though at lower rate compared to stratum four. Cyclic forest loss identified mainly in strata five along the Nile River and its tributaries and this is primarily part of sustainable forest management practices in RoS. Strata one and two are the desert and semi-desert area, only one sample was identified as a forest. Another significant activity observed is forest degradation the main driver of degradation is wood fuel and overgrazing activities. Table 11 provides area estimates derived from the current analysis at the state level. The analysis shows that Southern Kordofan exhibits the highest rates of deforestation and forest gain, followed by Southern Darfur. In contrast, the lowest rates of forest change are recorded in Western Darfur. no forest presence or related changes were observed in the Northern States, Red Sea, Gezira, Khartoum and River Nile states. The most significant forest degradation was observed in Western

Kordofan, followed by Southern Kordofan and Darfur. The overall confidence intervals for state-level estimates vary widely, ranging from 11% to 71%. These estimates are calculated using the equations outlined in section 5.4.

Table 11: Stratified Area Estimates by States in Hectares

Name	Forest Degradation	Forest gain	Forest loss	Other changes	Stable forest	Stable non forest	Total area (ha)
Blue Nile	58,477	75,565	102,318	21,977	1,167,525	2,382,186	3,808,048
Cantral Darfur	29,033	82,226	52,980	26,251	900,231	1,901,420	2,992,140
Eastern Darfur	94,222	166,865	158,116	123,075	1,935,964	3,801,227	6,279,468
El Gadarif	21,566	17,593	76,087	17,726	188,717	5,551,701	5,873,390
Gezira State	-	-	-	-	-	2,355,693	2,355,693
Kassala	3,029	11,095	74,914	6,657	13,688	5,242,495	5,351,878
Khartoum State	-	-	-	-	-	2,137,267	2,137,267
Northern Darfur	3,627	48,435	33,035	98,620	1,134,391	31,152,713	32,470,821
Northern Kordofan	-	10,151	185,558	38,261	202,037	17,108,146	17,544,153
Northern State	-	-	-	-	-	34,710,102	34,710,102
Red Sea	-	-	-	-	-	22,786,131	22,786,131
River Nile	-	-	-	-	-	13,210,477	13,210,477
Sinnar	43,330	60,645	52,357	11,095	575,684	2,997,066	3,740,176
Southern Darfur	151,610	188,496	424,989	98,392	3,068,465	4,322,995	8,254,948
Southern Kordofan	184,741	246,518	745,063	109,176	2,417,266	4,373,739	8,076,503
Western Darfur	17,751	23,320	33,791	26,036	375,170	1,948,085	2,424,153
Western Kordofan	206,535	147,639	423,512	300,529	2,594,935	8,053,002	11,726,152
White Nile	6,657	18,004	22,402	50,486	81,360	4,312,664	4,491,572
Grand Total	820,579	1,096,551	2,385,119	928,281	14,655,434	168,347,109	188,233,073

The majority of forest-related changes are concentrated in Southern and Western Kordofan followed by Southern Darfur and Eastern Darfur.

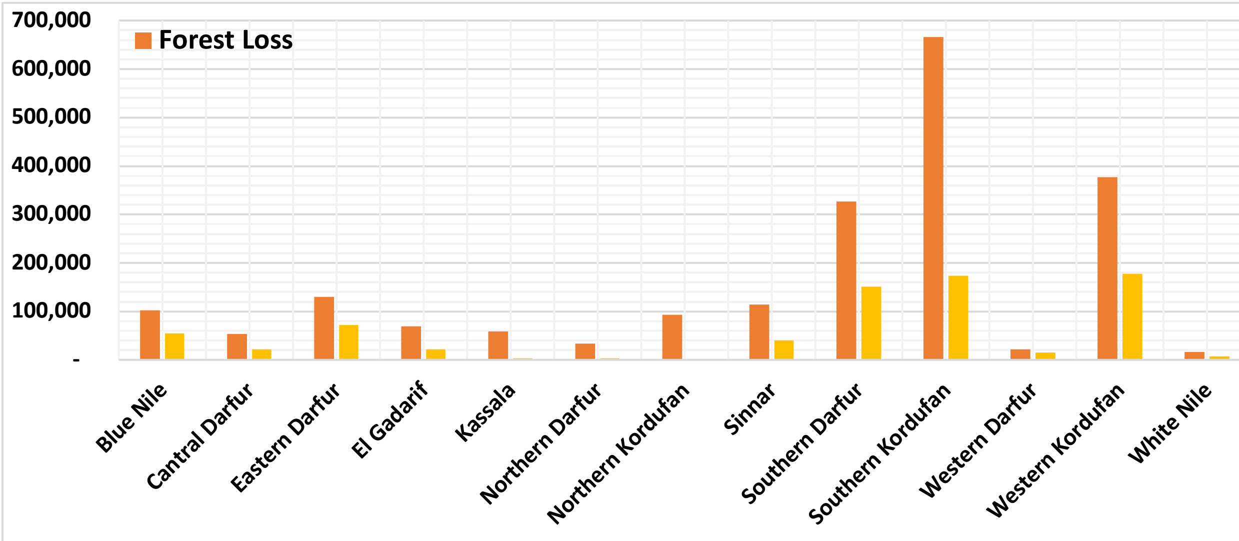


Figure 7: Showing trend of forest changes by states over 2012 -2021

Tables 12 and 13 below provide detailed annual estimates of deforestation (forest loss) and forest degradation by state.

Table 12: Annual Areas of Deforestation by State in Hectares

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Total
Blue Nile	-	-	7,255	21,353	10,471	14,099	3,627	10,471	7,255	20,943	6,844	-	-	102,318
Central Darfour	-	21,566	6,844	13,688	-	-	-	3,627	3,627	-	3,627	-	-	52,980
Eastern Darfour	20,532	21,566	17,939	11,095	32,880	3,627	3,627	6,657	-	18,349	14,722	-	7,122	158,116
El Gadarif	3,627	-	6,844	-	7,255	-	10,471	3,627	26,947	13,688	-	-	3,627	76,087
Kassala	12,225	-	27,557	3,627	7,122	6,657	-	-	-	10,471	3,627	3,627	-	74,914
Northern Darfour	-	-	-	12,225	6,844	13,966	-	-	-	-	-	-	-	33,035
Northern Kordofan	6,844	10,882	3,627	12,225	-	6,844	-	29,663	7,255	22,376	-	-	7,122	106,838
Sinnar	6,844	-	-	20,943	-	-	-	3,627	78,719	3,627	6,844	-	10,471	131,076
Southern Darfour	66,789	18,783	64,287	94,559	14,099	20,943	36,288	10,749	20,943	20,943	24,570	10,471	21,566	424,989
Southern Kordofan	36,075	53,588	114,795	65,717	50,584	56,607	86,051	75,154	77,550	53,588	32,235	18,137	24,981	745,063
Western Darfour	12,225	-	-	-	-	10,471	-	-	-	-	11,095	-	-	33,791

Western Kordofan	18,783	64,507	26,734	96,310	18,349	47,266	10,471	3,627	23,972	64,763	20,532	3,627	24,570	423,512
White Nile	3,029	-	-	3,029	-	-	-	3,627	3,627	3,029	3,029	3,029	-	22,402
Grand Total	186,974	190,892	275,882	354,771	147,604	180,480	150,536	150,831	249,895	231,778	127,126	38,892	99,459	2,385,119

Table 13 : Annual Areas of Forest Degradation by State in Hectares

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Total
Blue Nile	-	11,095	-	11,095	6,844	-	-	3,627	11,095	11,095	-	-	3,627	58,477
Central Darfour	6,844	11,095	-	-	-	-	-	-	-	11,095	-	-	-	29,033
Eastern Darfour	22,189	-	-	-	-	17,939	-	-	7,122	40,128	6,844	-	-	94,222
Gadarif	-	-	-	-	-	-	-	-	6,844	3,627	11,095	-	-	21,566
Kassala	-	-	-	-	-	-	-	-	-	-	3,029	-	-	3,029
Northern Darfour	-	-	-	-	-	-	-	-	-	3,627	-	-	-	3,627
Sinnar	-	3,627	-	3,627	-	6,844	-	-	14,722	7,255	3,627	-	3,627	43,330
Southern Darfour	-	11,095	35,254	36,911	-	6,657	-	11,095	14,722	24,783	11,095	-	-	151,610
Southern Kordofan	-	35,254	7,255	42,919	6,844	10,882	27,787	14,099	10,471	3,627	14,722	3,627	7,255	184,741
Western Darfour	-	-	-	-	-	3,627	-	11,095	-	-	-	-	3,029	17,751
Western Kordofan	21,566	6,844	24,783	64,287	-	6,844	39,915	6,844	17,315	7,255	3,627	-	7,255	206,535
White Nile	-	3,627	-	-	-	3,029	-	-	-	-	-	-	-	6,657
Grand Total	50,599	82,636	67,291	158,839	13,688	55,822	67,702	46,759	82,291	112,491	54,039	3,627	24,793	820,579

6.6. Quality Management

For quality management, five percent of samples from systematic grid were selected randomly by stratum for multi-interpretation. These samples were distributed among all participants, list of participants is provided in the Annex 9 of this report. After the data collection, analysis was performed in python where a customized script was developed for analysis. That mainly focused on agreement analysis among operators by LULC classes and change classes. Results were compared with overall average of aforementioned classes. The analysis showed a great variability among participants for both LULC and forest change classes. The performance was analysed by identifying top five interpreter with majority agreement for both LULC and forest change classes. The analysis showed that the overall average of LULC classes were found very close to the top five interpreters (Figure 9). However, the average of the top five interpreters in forest change classes was very low compared to overall average. The one conclusion that can be drive from this analysis is that change classes are generally very hard to interpret compared to LULC classes.

1- LULC Classes 2023 - Average

Class	Average
Cropland	22.50
Forest Land	16.50
Grassland	26.38
Other land	17.81
Plantation	2.50
Settlements	1.14
Wetland	1.09
(blank)	6.00
Grand Total	

2- First five Interpreters with majority agreement by LULC 2023

	Operator - 1	Operator - 2	Operator - 3	Operator - 4	Operator - 5	Average
Cropland	24	24	23	18	24	22.60
Forest Land	17	17	17	17	21	17.80
Grassland	29	29	30	28	26	28.40
Other land	13	13	13	20	15	14.80
Plantation	2	2	2	1		1.75
Settlements	1	1	1	1	1	1.00
Wetland	1	1	1	2		1.25
Grand Total	87	87	87	87	87	

3- Forest Change Classes 2023 - Average

Class	Average
Forest Degradation (F - F)	2.42
Forest Enhancement (F-F / NF - F)	3.38
Forest gain	2.50
Forest Loss (F - NF)	1.13
No Changes	73.13
Other changes	7.69
(blank)	3.50
Grand Total	

4- First five Interpreters with majority agreement by Forest Change Classes

Class	Operator - 1	Operator - 2	Operator - 3	Operator - 4	Operator - 5	Average
Forest Degradation (F - F)		1	1	1	1	1.00
Forest Enhancement (F-F / NF - F)						
Forest gain	1		1	1	1	1.00
Forest Loss (F - NF)	1	1		1		1.00
No Changes	81	81	80	78	79	79.80
Other changes	4	4	5	6	6	5.00
Grand Total	87	87	87	87	87	

Figure 8: *Showing comparison of top five interpreter average with overall average by LULC and forest change classes. 1- table one refers to LULC overall average by classes, table 2- is showing average of top five interpreter by LULC classes. 3- is showing forest change classes overall average 4 – showing an average of first five interpreters by forest change classes.*

<u>Agreement Matrix:</u> The table 14 presents a matrix illustrating the agreement among interpreters by LULC classes. The fractions in each column represent the agreement among interpreters, with "MOD" indicating the majority class identified during interpretation. The highest agreement is observed for the cropland class, where 82% of interpreters agreed. Whereas the agreement for forestland is 72%, as interpreters often found it challenging to distinguish between plantations and natural forestland. This difficulty arises because plantations in RoS are typically random in nature and lack the structured patterns observed in other countries, making them harder to differentiate from natural growth.

Table 14: Matrix of by LULC classes with majority agreement

Value Mode	Cropland	Forest Land	Grassland	Other land	Plantation	Settlements	Wetland
Cropland	0.817708	0.010417	0.104167	0.044271	0.020833		0.002604
Forest Land	0.031915	0.719858	0.230496		0.01773		
Grassland	0.040302	0.130982	0.715365	0.108312		0.005038	
Other land	0.066176		0.113971	0.8125	0.003676	0.003676	
Plantation	0.125	0.25			0.625		
Settlements	0.0625			0.0625	0.0625	0.8125	
Wetland		0.0625	0.0625	0.1875			0.6875

7. Description of the National Forest Inventory (NFI):

RoS's NFI (2021) is the main source of emission factors for deforestation. FAO through the technical assistance agreement with the World Bank and FNC has provided the technical support capacity resources for the NFI, NFMS/MRV and other related activities of the REDD readiness programme. The design used for the NFI is one that promoted by FAO and used in several countries. The field measurements of NFI (2021)[2] were conducted during the period 2017-2019 and the report was published in 2021.

7.1. NFI Sampling Design:

A systematic cluster sampling design was adopted for the NFI in RoS. Sampling Units were selected at the grid intersection of the latitude longitude degrees. The number of SU to be surveyed was determined by the available financial and human resources. Stratification was adopted as ecological zones were assumed to improve the design. RoS area was stratified into five strata. Sample Units (SUs) were allocated to each stratum according to vegetation density as shown in Figure 2 above. Initially, a total of 1755 SUs were planned, then reduced to 968, and finally 784 SU were visited, the rest were inaccessible due to security or physical reason.

Data is collected in the field through observations, measurements and interviews at different levels within the limits of the sampling units (SU) and in smaller subunits, the plots, subplots, Land

[2] Full description of NFI (2021), is found at: https://www.fao.org/fileadmin/user_upload/faoweb/Themes__pages/Forests/REDD-NFM/RoS_MRV/RoS_-_NFI_Report.pdf

Use/Cover Sections (LUCS) and Land Use/Cover Classes (LUCC) demarcated within the sampling units, see Annex 3.

- A **sampling unit (SU)** or "Tract" is a square surface area of 1 km x 1 km. The coordinates of the south-west corner of the Sus correspond to those of the points selected in the systematic sampling frame. Each SU contains **four** field plots, which means in total 3136 (784x4) plots have been surveyed in this NFI cycle.
- The **plots** are rectangles, with surface areas measuring 20 m wide and 250 m long (area 0.5 ha) within the SU. They start at each corner of an inner 500 m square (same centre as SU's), and are numbered clockwise from 1 to 4.

Each plot is divided into Land Use/Cover Sections (LUCS) identified in the field as shown in the example below. Data related to grazing, cropping and forest characteristics, management and resources use and users are collected within the LUCS.

Figure 4: An example of Land Use/Cover Sections (LUCS) distribution within a plot

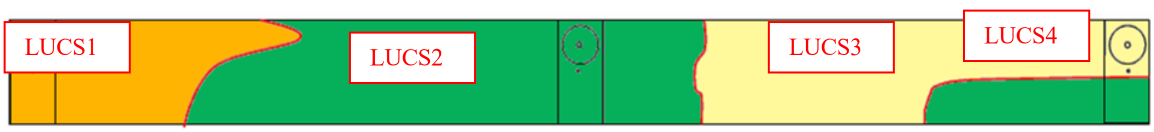


Figure 9: Land use Land Cover Section

7.2 Data Collection Process

Data are collected by the field teams for SUs, plots, subplots, measurement points, land use/cover section (LUCS), land use/cover class (LUCC) and interviewees. The main information sources for the assessment are:

- Field measurements and observations.
- Interviews with key informants (external and internal), focus groups and individuals and randomly selected households.

Different variables are collected depending on data collection levels:

- **Plot**: identification of different land use/cover sections (LUCS) and measurements of trees and stumps with a Dbh ≥ 20 cm in forest, or ≥ 10 cm for the trees outside forest. A plan of the plot indicating in particular land use/cover sections limits must also be completed.
- **Land Use/Cover Section (LUCS)**: corresponds to the land use/cover sections identified

along the plot. Information collected at this level includes: general information related to the LUCS**;** forest and other wooded lands management practices (harvesting, silviculture, etc.); and structure, as well as crop management practices.

- **Land Use/Cover Classes (LUCC):** corresponds to each land use class found in the SU (in all 4 plots). Information on forest and trees, on environmental services, pests and diseases, invasive and threatened species, wildlife abundance, and land use change is collected at this level.
- **Rectangular Subplot (RSP):** shrubs (in all LUCC), trees with 20 cm > Dbh ≥ 10 cm trees (only in forest LUCC), indicator plant species and non wood forest products (NWFP) are inventoried at this level.
- **Circular Subplot (CSP)**: data on tree regeneration (Dbh < 10 cm and height ≥ 1.30 m) data are collected at this level (only in forest, OWL and woodlots) .
- **Litter Subplot (LSP)**: at this level, data is collected on litter, which includes all non-living biomass with diameter less than 10 cm.
- **Fallen Deadwood Transect (FDT)**: measurements of fallen deadwood branches (≥ 10 cm) are done along the transect lines.
- **Measurement point (MP):** topographic and soil data is collected at the three measurement points**.**

7.3. Data Analysis

The information of the NFI field survey was stored in files (e.g. trees >10 cm, small trees<10cm, stumps, etc) using the Open Foris Collect platform. Silva Metricus software have been used to perform calculations based on these files, Annex 4 provide the description of the NFI data analysis, calculation and the procedures used in driving the estimates of the NFI data including the volumes estimates used in this submission.

During the fieldwork stage, every effort was made to minimize measurement errors through training processes for the crew members, as well as the use of the best available measurement instruments. This is in addition to the review and quality checks performed twice for data entry, cleansing, transition to software and recalculations. The software Silva Metricus was used for the calculations of the sampling errors following the approach of “ratio estimator”.

At the national level, the overall variability of the NFI is very low, e.g. 9.11% for the forest land, because all the 784 Sampling Units are considered. However, when the calculation is disaggregated to State level, the number of sampling units included in the calculation of each State decrease and therefore the variability increase (see table 15 below).

7.4. Emission Factors for Deforestation:

Emission factors for deforestation have been developed, mainly based on the NFI data, for all the states with deforestation (13 states). Table 15 below shows the NFI volume per hectare of live trees, small tree (>10 cm) and standing deadwood. NFI (2021) including data for all these states except two the states of Kassala and White Nile states. The missing data for these states is due to the fact that during the NFI ground survey, the field survey teams could not cover all the targeted SUs as explained earlier, there are about 184 unvisited Sus, because of security and other reasons (e.ge terrain). As part of this FRL project, a plan was included to take measurements from the NFI unvisited SUs in order to improve the emission factors. However, because of the current war situation this also was not possible. Therefore, RoS requested support from Maryland University through FAO to explore using their Global Ecosystem Dynamics Investigation (GEDI) technical resources, to gap-fill RoS's NFI, missing sample-units (SUs). The results of this collaboration is currently under discussion by relevant departments of FNC with a view of including it as an addendum to the NFI report. The GEDI data estimates are based on a model developed for RoS and calibrated using the actual NFI data, Annex 7 show the GEDI data and for the description of the methodology information is available at: https://www.sciencedirect.com/science/article/pii/S0034425724005832. Discussion still going on with Maryland University to explore possibility of developing data for estimating emissions from forest degradation.

Table 15: Average aboveground volume/hectare (v/ha) of forestland disaggregated by state

States	Big trees (m3/ha)	Sampling error (%)	Small trees (m3/ha)	Sampling error (%)	Standing Deadwood (m3/ha)	Sampling error (%)
North Darfour	2.8	42.9	1.0	55.7	0.2	155.4
South Darfour	21.0	15.4	3.2	23.2	5.0	61.3
West Darfour	5.3	69.3	0.9	71.3	1.9	147.3
East Darfour	19.6	20.4	1.8	31.5	2.2	67.3
Central Darfour	17.1	18.8	1.8	30.9	2.0	81.3
North Kordofan	4.0	83.0	0.6	55.7	0.8	114.0
South Kordofan	16.6	21.6	1.6	38.6	2.6	47.7
West Kordofan	19.0	15.4	0.5	26.3	2.9	29.1
Blue Nile	18.2	46.7	3.6	39.1	0.9	140.8
Sinnar	20.9	51.5	1.2	78.4	1.2	121.7
Gadarif	3.6	96.3	2.8	86.2	0.0	136.2

Source: NFI (2021) data

Emission factors for each state have been estimated following the 2006 IPCC Guidelines, in particular equation 2.15 of Chapter two, with country-specific data of stock density (V/ha) obtained from the NFI (2021) data. Wood density data has been obtained from various sources including country specific data from national research, FAO, African Wood density Database of World Agroforestry Centre, Ethiopia FRL submission (2017) in addition to the IPCC 2006 guidelines (see Annex 2 of this submission). The wood density values obtained from these sources are representative of RoS's forest circumstances. Weighted average wood density values have been calculated for each state based on the main tree species that represent more than 80% of the total wood volume in State (see table 16 below). The number of the main tree species per states vary between 7-19 species. In RoS's view this approach gives more representative values of wood density for a more accurate estimation of the emission factor for each state.

Table 16: Weighted Average Wood Density Values of the main Tree Species per State

States	Weigthed Averag. WD t. d.m/m^3	No of main Species used in the calculation
North Darfour	**0.63**	19
South Darfour	**0.72**	18
West Darfour	**0.70**	18
East Darfour	**0.71**	18
Central Darfour	**0.69**	18
North Kordofan	**0.64**	19
South Kordofan	**0.73**	18
West Kordofan	**0.71**	18
Blue Nile	**0.64**	18
Sinnar	**0.69**	9
Gadarif	**0.64**	7

Other default data for root shoot ratio (0.332) of the tropical dry African region was obtained from the 2019 Refinement IPCC Guidelines table 4.4. and the carbon fraction (0.47) obtained from the 2006 IPCC Guidelines table 4.3. Table 17 below shows the emission factors of the different States calculated based on the above explained data and parameters. Uncertainty of the volume per hectare (NFI) and other default parameters have been propagated using 2006 IPCC methodology.

Table 17: Emission factors for deforestation

States	Emission Factor (tCO_2/ha)	Uncertainty 90% CI
Blue Nile	33.15	58%
Central Darfour	33.01	38%
East Darfour	38.58	39%
Gadarif	9.52	91%
Kassala	3.05	149%
North Darfour	5.87	54%
North Kordofan	7.97	91%
Sinnar	36.65	68%
South Darfour	48.46	40%
South Kordofan	34.94	39%
West Darfour	13.16	90%
West Kordofan	36.70	36%
White Nile	2.50	133%

8. The Activity Data for Enhancement of Forest Carbon Stock:

The activity data (AD) for estimation of the removals associated with the enhancement of forest carbon stocks due to Afforestation and Reforestation (A/R) has been obtained from the Forest National Corporation (FNC) HQ and its offices in the States. FNC has an official annual A/R programme which is being implemented on bare lands in degraded forest areas, in addition to afforestation activities on the agriculture schemes (cropland) in collaboration with farmers and local communities. FNC keeps good records of the annually planted A/R areas, based on annual reporting by FNC state-level offices and reports of supervision visits conducted to assess the implementation of these annual A/R activities. With the support of the FRL Taskforce (FRL TF) data of the annual A/R areas has been collected for the years of reference period (2012- 2021), disaggregated by states. The AD is also disaggregated by A/R implemented through seeds and seedings. Data verification, quality checked of errors and missing records was performed using data from the State offices of FNC and through the consultation with the FRL TF members. Modifications have been made to the land area data to cover some of the missing records for West Kordofan State, which was established in year (2013) of the reference period to cover missing records of years 2012 and 2013. The modification was based on a simple assumption that the total annual A/R areas for year 2012 and 2013 planted by North and South Kordofan States are shared equally with the new state of West Kordofan, which is established on part of the land areas of North and South Kordofan States. Accordingly, a complete set of annual A/R area data has been obtained for all the 18 states of RoS for the years of the reference period (2012-2021), see Annex (1). In this data set, zero records in some years mean A/R activities have not been implemented.

Overall, the area planting through use of seeds represents about 90%, while the area planting through seedlings represents the remaining 20%, of the total area of the annual A/R activities in RoS. However, the success rate of the area planting by seeds is very low compared to the to the area planted by seedlings. This is generally attributed to lack of sufficient investment in the areas planted by seeds, including for land preparation, water harvesting, protection against grazing and other treatments such as weeding which is usually practiced once or twice to reduce weed competition. Planting by seeds in many cases is done simply through seeds broadcasting without any land preparation or other treatments. Higher success rates are to a large extend associated with the A/R areas supported through some donor funded projects, in which more investment is made including on nurseries, land preparation and other practices. Generally, data on success rate was difficult to obtain given the war circumstances in RoS and lack of access to the data in the buildings of FNC HQ and some state offices. In fact, FNC data does not conduct assessment of success rate of the annual A/R plantations for more than one or two years after their planting date. Accordingly, the available records may not be representative of the actual or average success rate of the A/R forests over the reference period. Therefore, estimates of the overall success rate of the annual A/R areas planted by seeds and seedlings has been obtained based on expert judgement, involving use of some of the data available in state offices, the expertise of the FNC staff working in the states and also in consultations with the members of the FRL TF. The estimates agreed on the average success rates of the A/R areas planted by seeds and seedling are presented in the table (18) below:

Table 18: Success rates of A/R forests planted by Seeds and Seedlings for each State

State	Success rate (Seeds) %	Entries used	Success rate (Seedlings) %	Entries used
Northern	25	**0.25**	68-70	**0.69**
River Nile	40-44	**0.42**	77	**0.77**
Khartoum	20-30	**0.25**	80	**0.80**
Al-Gezira	50	**0.50**	75	**0.75**
Sinnar	25-30	**0.28**	75	**0.75**
White Nile	45	**0.45**	60	**0.60**
Blue Nile	30-35	**0.33**	70-75	**0.73**
Gadarif	30-40	**0.35**	75	**0.75**
Kassala	35	**0.35**	70	**0.70**
Red Sea	20-30	**0.25**	70	**0.70**
North Kordofan	20-30	**0.35**	60	**0.60**
South Kordofan	50	**0.50**	53	**0.53**
West Kordofan	38	**0.38**	57	**0.57**
North Darfour	20-30	**0.25**	65-70	**0.68**
South Darfour	46	**0.46**	70	**0.70**
East Darfour	42-50	**0.46**	65-75	**0.70**
West Darfour	45-50	**0.48**	75-80	**0.78**
Central Darfour	35-45	**0.40**	70-80	**0.75**

A range of more than 12 multipurpose tree species are used by the different States of RoS in their annual A/R activities. These include tree species planted for nontimber forest products (NTFP) such as Gum production, other forest fruits, animal fodder and tree planted for round wood, timber, shade, etc. Different States use different combinations from these 12 tree species and plant them in different areas of their annual A/R programme area, this is in accordance with their local needs, climate, circumstances and objectives. Table 19 below include information on the names of the tree species used and the percentage of their areas from the total annual A/R area in the different States.

Table 19: Common tree Species used in the annual A/R activities and percentages of their areas in each State

States	Acacia senegal	Acacia seyal	Acacia nilotica	Acacia tortilis	Acacia mellifra	Khaya Senegalensis	Eucalyptus Spp	Balanites aegyptiaca	ziziphus spp	Azadirachta indica	Dalbergia sissoo	Sclerocarya birrea
Khartoum			5	75			20					
Al-Gezira		10	30	35	20		5					
Sinnar	25	30	35		10							
White Nile	30	20	20	15	15							
Blue Nile	50	15	25		5	5						
Gadarif	10	62	10		10		3					
Kassala	42	45	2	4	2		5					
Red Sea				40	5			20	30	5		
N. Kordofan	62	5	5	10	10			4	4			
S. Kordofan	50	20	5		20							5
W. Kordofan	75	5	10		5			5				
N. Darfour	62		5	23	10							
S. Darfour	40				15	30				5	10	
E. Darfour	60	30			5	5						
W. Darfour	30		5		50					10		
C. Darfour	50		10		30	5			5			
Northren		15	8	40	2		35					
River Nile		20	10	42	10		15			3		

8.1. Removal Factors for Enhancement of Forest Carbon Stock:

Removal factors and other parameters for estimating the Enhancement FRL are obtained from FNC activity data records in addition to the IPCC default data. Data on annual growth rates of the species used in A/R is not available from national sources. The NFI (2021) report does not provide such data. Therefore, RoS used representative default Mean Annual Increment (MAI) values from table 4.11 of the 2019 Refinement IPCC Guidelines, which provides MAI values for almost all the native tree species used in RoS and this data is represents African conditions, except for *Azadirachta indica MAI* value, which was obtained from FAO data.

When selecting the MAI value for the A/R tree species, RoS selected MAI values of "Productive semi-natural forests", because are representatives of the circumstances of its A/R forest formations that consist of productive native tree species, planted mostly by seeds on bare, degraded areas and generally take similar shape and provide the same function, as of the natural forest formation.

The wood density values of the main species used in A/R activities have been obtained from different sources including national research, the World Agroforestry Center, African Wood Density Database, etc, see Annex 2. The values of the root-shoot ratio are from 19R IPCC Guidelines table (4.4) and the Carbon Fraction from 2006 IPCC Guidelines table (4.3). Value of Biomass Expansion Factors (BEF) used in equation 2.10 was obtained from table 3A.1.10 of the IPCC GPG-LULUC (BEF1 values).

It is worth mentioning that in RoS's subnational FRL 2020, BEF values have not been used in the estimation of the A/R removals. However, in estimation of this FRL, it is noticed that the MAI data of table 4.11 of the 19R IPCC guidelines represents merchantable volume and not the total aboveground volume. Therefore, BEF1 value of the tropical broad leaf forest type has been used with wood density values to expand the merchantable volume to the total aboveground biomass. Table 20 below shows the parameters used in the estimation of the removal associated with forest enhancement activities in RoS.

Table 20: Mean Annual Increment values and other parameters used in estimation of A/R removals

Common species used in A/R activities	**Growth rate** 19R IPCC table 4.11		**Wood Density**	**Biomass Expansion factor (BEF1)**	**Root shoot ratio**		**Carbon Fraction**
	Mean Annual Increment (m3/ha/yr)**	St. Dev	t. dm/m3	Table 3A.1.10 GPG LULUCF	19R IPCC table 4.4	St. Dev	2006 IPCC table 4.3 tC/t. dm
Acacia nilotica	12.5-20	1.9	0.8	1.5 (1.3-1.7)	0.332	0.247	0.47
Acacia seyal	1.8-3.2	0.4	0.7	1.5 (1.3-1.7)	0.332	0.247	0.47
Acacia senegal	1.1-2.4	0.3	0.7	1.5 (1.3-1.7)	0.332	0.247	0.47
Acacia mellifra	1.9-3.5	0.4	0.7	1.5 (1.3-1.7)	0.332	0.247	0.47
Acaica Tortilis	1.2-3.7	0.6	0.44	1.5 (1.3-1.7)	0.332	0.247	0.47
Khaya Senegalensis	8.5-12	0.9	0.7	1.5 (1.3-1.7)	0.332	0.247	0.47
Euclyptus Spp	10-14	0.5	0.6	1.5 (1.3-1.7)	0.332	0.247	0.47
Balanites aegyptiaca	1.2-1.5	0.1	0.63	1.5 (1.3-1.7)	0.332	0.247	0.47
ziziphus mauritiana	0.9-1	0	0.6	1.5 (1.3-1.7)	0.332	0.247	0.47
Sclerocarya birrea	1.5-1.7	0.1	0.8	1.5 (1.3-1.7)	0.332	0.247	0.47
Dalbergia sissoo	4-6	3.8	0.6	1.5 (1.3-1.7)	0.332	0.247	0.47
Azadirachta indica	(4-19) 5 averg *	0.5	0.8	1.5 (1.3-1.7)	0.332	0.247	0.47

*https://www.fao.org/4/y9933e/Y9933E12.htm

**RoS used average values from the range in table 4.11

Based on these data sets, removal factors have been calculated for each state, representing a weighted average annual increment per hectare of the combination of the species and the percentage of their areas in the annual A/R progamme of each state. Uncertainty of the MAI and other parameters used in the calculation of the removal factors, has been propagated. However, FNC data on annual A/R areas do not include uncertainty values, therefore, it assumed zero. Hence, the uncertainty values here represent only uncertainty associated with the MAI and other parameters used in the estimation of the removal factors. Table (21) below contains the removal factors used in the estimation of the Enhancement FRL for each State.

Table 21: Removal Factors, Weighted Average Annual Biomass Carbon Increment

State	Weighted Average Annual Removal in A/R areas	
	(tCO_2/ha/year)	Perc 90% CI
River Nile	11.92	18.4%
Northren	14.78	21.4%
Khartoum	9.98	21.8%
Red Sea	3.50	32.8%
Kassala	6.90	19.4%
Gadarif	10.24	21.1%
Blue Nile	15.76	25.8%
Sinnar	18.77	29.7%
Al-Gezira	17.87	27.7%
Wihte Nile	12.96	25.1%
North Kordofan	6.37	20.8%
South Kordofan	7.54	17.7%
West Kordofan	8.41	23.8%
North Darfour	6.36	21.4%
South Darfour	11.97	22.6%
West Kordofan	7.91	22.8%
East Drafour	5.90	21.6%
Central Darfour	9.87	19.9%

9. APPROACHES AND METHODS APPLIED IN THE FRL CONSTRUCTION

The IPCC 2006 National GHGs Inventory Guidelines does not directly refers to the REDD+ activities. However, the UNFCCC decisions (4/CP.15 and 12/CP.17) require Parties to use the most recent IPCC Guidelines and to maintain consistency with their GHGs inventory in the estimation of FREL/FRL and REDD+ results. Accordingly, IPCC methodologies are widely used by all REDD countries in the construction of FREL/FRLs and estimation of the REDD+ results. RoS applies the 2006 IPCC Guidelines in the estimation of emissions/removals associated with the two REDD activities of deforestation and enhancement of forest carbon stock, taking into consideration its national circumstances.

9.1. Estimation of GHGs Emission from Deforestation:

Deforestation is calculated as the net average annual carbon emissions associated with forestland converted to non-forestland (mainly to cropland) over the reference period (2012- 2021), disaggregated by the States. RoS applies the 2006 IPCC guidelines equations 2.15 and 2.16 of Chapter 2, in the estimation of the emission associated with deforestation, as applicable in the circumstances of RoS.

The net average annual carbon emissions of deforestation is equal to the sum of the biomass carbon stock on the forestland areas converted to other land use in all States. Assuming the oxidation of all the biomass removed from these forest areas in the same year, because in RoS forests are mainly converted to annual cropping system, the removed wood is used for energy purposes, either directly as fuelwood or converted to charcoal, and is consumed in the same year. Accordingly, the estimation of net average annual emissions associated with deforestation follows the steps below:

Step 1: Obtain the annual area of deforestation, forestland converted to other lands (ATO_OTHERS), to be used in equation 2.16 of the 2006 IPCC Guidelines. Data of annual deforestation (forest loss) has been obtained using remote sensing data as described in section 6 above.

Step 2: Calculate the carbon stocks change per area for the type of conversion (to cropland) applying equation 2.16 of the 2006 IPCC Guidelines. Values of carbon stocks in biomass immediately after conversion (B_{After_i}) are assumed to be zero, since the land is cleared of all its forest vegetation before it is turned into annual crops cultivation. In subsequent years after the conversion, change in biomass carbon stock of annual crops is considered zero because carbon gains in biomass from annual growth are offset by losses from harvesting. RoS's has an annual cropping system in the rainfed sector of a of 3-6 months rotation, dominated by crops such as different varieties of sorghum and millet, sesame, sunflower, groundnuts.

1. Equation (2.16): Estimation of Change in Biomass Carbon Stock on Land Converted to Another land Category (mainly to Cropland).

$$\Delta C_{Conversion_i} = \sum_i \{(B_{After_i} - B_{Before_i}) * \Delta A_{To-Others_i}\}$$

Where:
$\Delta C_{Conversion_i}$ = Change in biomass carbon stocks on land converted to another land category, tonnes CO_2/Year
B_{After_i}= Biomass stocks on land $type_i$ immediately after the conversion, tonnes d.m. ha-1
B_{Before_i}= = biomass carbon stocks on land type i before the conversion, tonnes t.CO_2/ha
$\Delta A_{To-Others}$ = area of land converted to another land-use category in certain year, ha/year
i = State

2. Calculate Initial biomass carbon stocks on Forestland converted to Cropland (equation 2.10)

$$B_{Before_i} = V_{AG_i} * WD_i * (1 + R) * CF * 44/12$$

Where:
B_{Before_i}= Biomass stocks on forestland $state_i$ before the conversion, tonnes CO_2/ ha
V_{AG_i} = above ground volume m3 /ha (RoS's NFI 2021 data, see table 13 above)
WD_i= weighted average wood density t. d. m /ha (table 14 above)
i = State
R = Root – shoot ratio (table 4.4, 19R IPCC Guidelines)
CF = Carbon fraction of dry matter, tonne C (tonnes d.m.)-1
44/12 = The ratio of molecular weights to convert C to CO_2

Step 3: Sum up all the annual changes in biomass carbon stocks due to deforestation all the States.

9.2. Estimation of Removal from Enhancement of Forest Carbon Stock:

Enhancement FRL is estimated as the average annual accumulated CO_2 removals from the A/R activities on cropland and bare land in degraded forest areas (mainly subjected to cultivation), over the reference period (2012-2021). RoS applies methods of the IPCC 2006 guideline for estimation of changes in biomass carbon stocks associated with A/R activities in these lands. In particular, RoS applies equations 2.10 and 2.9 as applicable in circumstances of RoS. The annual removals are estimated disaggregated by States and by A/R implemented by Seeds and Seedling separately. The total removal will equal the sum of the removals in all States, as follow:

$$\boldsymbol{Total\ CO2\ removal} = \Delta \boldsymbol{C}_{\boldsymbol{G}_{\boldsymbol{STATE1}}} + \cdots + \cdots + \Delta \boldsymbol{C}_{\boldsymbol{G}_{\boldsymbol{STATE18}}}$$

Step 1: Obtain data on the area converted to Forest Land. The data on annual A/R areas was obtained from the records of the Forest National Corporation (FNC) HQ and State offices. The data is disaggregated by states and by areas planted by Seeds and areas planted by Seedlings. See Annex 1.

Step 2: Obtain data on the tree species used, their area percentage of the total annual A/R areas and the success rates for A/R forests by Seeds and A/R by seedling. This data represents the best estimates, based on some of the available FNC records (in states), expert observations and opinions from FNC staff at the different states, in addition to the consultation with the member of FRL TF. See tables 16 and 17 above

Step 3: Estimate average annual increment of biomass carbon stock, separately for A/R planted by Seeds and Seedlings, weighted by the area of each species used in the different States (see table 19 above). Equation 2.10: Average annual increment in biomass

$$G_{Total_j} = \sum \left\{ I_{V_i} * D_i * BEF_{I_i} * (1 + R_i) * CF * 44/12 \right\}$$

Where:

G_{Total} = average annual biomass growth above and below-ground, tonnes CO_2/ha/year
I_V = average net annual increment for specific vegetation type, m3 ha/yr
D = basic wood density, tonnes d.m. m-3
BEF_1 = biomass expansion factor for conversion of annual net increment (including bark) to aboveground tree biomass increment, dimensionless; Table 3A.1.10 GPG-LULUCF
R = ratio of below-ground biomass to above-ground biomass for a specific vegetation type, in tonne d.m.
i = Species and
j = State
CF = carbon fraction of dry matter, tonne C (tonne.dm.)-1
44/12 = The ratio of molecular weights to convert C to CO_2

Step 4: Estimate the average annual increment in carbon stocks due to biomass growth (ΔC_G), accumulated in the annual A/R areas over the period 2012-2021, using Equations 2.9 of Chapter 2 of the 2006 IPCC Guidelines.

Equation 2.9: Average annual accumulated biomass carbon stock in the annual A/R areas.

$$\Delta C_{G_{STATE}} = \sum_{i,j} \left(A_{i,j} * G_{TOTAL} * Succ.rate_{i,j} \right)$$

Where:

$\Delta C_{G_{STATE}}$ = Average annual accumulated biomass carbon stocks on the annual A/R areas, tonnes CO_2/Year
A = area of annual A/R planted by Seeds and Seedlings, ha
$G_{Total_{i,j}}$ = mean annual biomass growth, tonnes CO_2/ha/year
Succ. rate = percentage of the survival rate of the A/R plantation, see table 16 above
i = A/R area by seeds
j = A/R area by seedlings
STATE: Government subnational administrative level. RoS has 18 States

Biomass loss due to wood removal or disturbance, in the A/R established forests is very unlikely to happen during the reference period, (trees will be 10 years old) and therefore, has not been including in the estimation of the annual removals. Wood harvesting in RoS happens only on forest plantations managed for specific rotation periods ranging, according to species, from 15 years to the maximum natural age of the tree species used in A/R. The specific objectives include protection of watershed, production of wood, timber and none wood forest product such as Gum Arabic, the latter is very common in most of the forest. Tree species such as Acacia Senegal and Acacia Seyal which are commonly used in most of the States, are mainly managed for production of Gum. These two species in addition to A. mellifera, A. tortilis and others are also very important as animal fodder. Timber producing tree species such as Acacia nilotica and Mahogani are usually grown for more longer rotations, 25 year and above. Direct fuel wood collection by local people communities, is common in RoS, however, is mostly from deadwood in the natural forests and some mature plantation forests, therefore wood collection is not expected to happen in these 10 years old A/R forests.

Fires are important disturbance in RoS, however, according to NFI 2021, in most of the forest area in RoS there is no evidence of fire, only about 3.63% of the total forest area experienced burning. The most common type of fires is the surface fire, which represent about 92.1% of the burnt area, while crown fire represents only about 0.18% and the rest (about 7%) such as underground fire. According to the national fire management strategy framework (2021), fires in RoS are human induced (not natural fires) and are mostly surface fires, which burns surface litter, other loose debris and small vegetation and usually cause least damage to forests. The forest burnt areas are insignificant compared to the total burnt areas in country. This is might be attributed to high incidences of fire outbreak in dense grass area (savannah woodland) rather than forestland. Most of forest burn areas were found in Blue Nile, South Kordofan and South Darfur States. Fires incidences on A/R forest area are very unlikely because usually these are managed and better protected through fire lines. Regular data on fires monitoring is needed for the inclusion of possible emissions from fires in the national FREL/FRL, currently such data is not available.

10. RELEVANT POLICIES AND LEGISLATION

Forestry activities started in the RoS in 1901, when the Woods and Forests Ordinance was promulgated and the Department of Woodlands & Forests was established the same year. Adoption and implementation of administrative and legislative measures continued ever since. The first forest policy for the RoS was enacted in 1932 with a main objective to protect and reserve country forests resource. The policy included directives on afforestation and logging activities in and outside of reserved areas. Also, stated the prohibited actions in forests and outlined privileges and rights of the population in and surrounding the forests.

The Forest Act of 1932 divided the responsibilities of forest administration between the central and provincial authorities. In 1939 a royalty order was enacted for collecting royalties from forest products produced outside the forest reserves to discourage people from cutting trees outside the forest reserves.

In 1986, the revision of the 1932 policy was made to accommodate the constitutional, political, administrative, environmental and socio- economic changes. The revised policy of 1986 also recognized and encouraged establishment of private, community and institutional forests (including irrigated forest plantations in agricultural schemes). The policy stressed the role of people participation and forestry extension in the areas of forest plantation, management and protection. It provided clear directions to raise the total areas of natural forests, wildlife reserves, and range lands. Its main objectives were to reserve 20 percent of the total area of the country, manage the forest resources on sustainable basis, strengthening institutional capacity. In addition, to resolving inter-sectoral conflicts, which have been a major cause of deforestation.

The Forests Act 1989, since its promulgation, has been repeatedly praised as the most important piece of legislation in RoS. It legalized people's participation in forest management and recognized, under the FNC technical supervision, new types of forest ownership: private, community and institutional forest reserves to be managed by owners, committees and institutions respectively, in addition to the national and regional forest reserves.

The current Act of Forests and Renewable Natural Resources, 2002 (FRNR), provides the framework for integrated management and protection of forests and renewable natural resources encompassing pasture and range. The Act also obliges investors in agricultural schemes to leave not less than 10% of the total area of a rainfed project and not less than 5% of the area of an irrigated project as shelter belts and protective wind breaks.

The Forest National Corporation has been established by the Forest Act (1989). Among the missions of the FNC is to develop and implement public policies, rules, plans and methods for safeguarding and protection of the forest resources. FNC responsibilities include technical supervision of the forest resources, building awareness, promote afforestation and reforestation including development of the Gum Arabic and other forest products. FNC is currently responsible for the development and implementation of the national REDD+ programme.

11. PROPOSED FROREST REFERENCE LEVEL

The RoS national Forest Reference Level includes the two REDD+ activities of reducing emissions from deforestation and the enhancement of forest carbon stock. The reference period for both REDD+ activities is the same (2012-2021). Deforestation is identified in 13 states with forest resources. Over the reference period deforestation causes total net average annual emissions estimated at **6,932,496 t.CO_2/year** with uncertainly value of 13%, see table 22 below. On the hand, there are potential land available in all the states for implementing activities of afforestation and reforestation (A/R) to enhance of forest carbon stock. During the reference period the A/R activities have resulted in a sum of average annual accumulated removals estimated at **2,108,584 t.CO_2/year,** see table 23 below, with uncertainty value of 7.34% however, this uncertainty estimates represent only the uncertainty of removal factors and related parameters as explained in section 8.1. and table 21 above.

Table 22: Proposed Values of the Deforestation FREL

States	Net Average Emissions from Deforestation	
	t.CO_2/Year	CI 90%
Blue Nile	339,181	24%
Cantral Darfur	174,904	54%
Eastern Darfur	503,349	28%
El Gadarif	65,517	90%
Kassala	18,032	87%
Northern Darfur	19,406	56%
Northern Kordofan	74,020	50%
Sinnar	416,879	68%
Southern Darfur	1,580,621	43%
Southern Kordofan	2,326,325	19%
Western Darfur	28,391	184%
Western Kordofan	1,381,781	15%
White Nile	4,089	378%
Total	**6,932,496**	**13%**

Table 23: Proposed Values of the Enhancement of Forest Carbon Stock FRL

State	Average Accumulated Annual Removal (t.C02/year)
River Nile	– 58524
Northern	– 39556
Khartoum	– 193
Red Sea	– 6860
Kassala	– 21827
Gadarif	– 131301
Blue Nile	– 41554
Sinnar	– 112758
Al-Gezira	– 97137
Wihte Nile	– 126349
North Kordofan	– 417151
South Kordofan	– 292097
West Kordofan	– 393040
North Darfour	– 49143
South Darfour	– 149194
West Darfour	– 83175
East Drafour	– 46267
Central Darfour	– 42456
Total FRL Value	**– 2,108,584**

12. ADJUSTMENT FOR NATIONAL CIRCUMSTANCES

With splitting of Sudan in 2011 in two States, about half of the forest resources become part of the new state of South Sudan, while about two third of the population remains in RoS. This situation resulted in increasing pressure on the remaining forest resources and raised the need for improvements in policy, planning and management practices to respond to the new situation. The national REDD programme, which was initiated (2013) comes at an opportune time to review policy, institutional framework, assesses the forest resources and the related social and environmental frameworks. The processes and outcomes generated by the national REDD readiness programme enabled addressing most of the challenges and improvements needed to make the forest policy framework, planning and management practices relevant to addressing the circumstances created by the separation of South Sudan and responding to climate obligations. These include adoption of a National REDD Strategy, new forest definition, conduct of a NFI, development of MRV/NFMs and building of technical and institutional capacity within FNC and REDD related institutions at the national and subnational (state) level. The reference period selected for this FRL (2012-2021) considered representative of the current trend in terms of capturing the effect of all these national circumstances affecting forest sector. Accordingly, RoS does see the need to further undertake an adjustment to the proposed FRL in this submission. However, further work on the effects of policy development on forest management and implementation of REDD+ activities will be studied in the future updates of the national FREL/FRL.

13. UPDATING FREQUENCY

The national FRL will be updated when there are relevant improvements in the methodologies, activity data and other parameters (e.g. NFI, remote sensing and national research). Development in RoS's climate obligations relevant to the forest and land use sectors and development in the international REDD+ framework are also important consideration in the assessment of needs for future updates of the FRL.

14. FUTURE IMPROVEMENTS

Following the stepwise approach of REDD+ framework, RoS moved from the subnational FRL developed in 2020 to prepare a national FRL. The preparation of the national FRL has benefited from the knowledge, resources, data and experience developed during the preparation of the subnational FRL, including the feedback from the UNFCCC TA in 2020. However, RoS could not implement most of the findings on improvement provided by the UNFCCC TA. This is in part because there has been no significant change in the national circumstances regarding data during the short time since the TA of the 2020 FRL and also because of the exceptional political and unrest situation during this period including the current war situation.

Activity Data: Resources permitted, FNC to integrate the Activity Data (AD) methodology used in the FRL submission into the National Forest Monitoring System (NFMS), to ensure that the system is regularly updated to reflect changes in forest activities. There is a need to strengthen the capacity of the RoS team in data collection and reporting processes, as an effort to improve both transparency and accuracy. There is a need for national definitions of all REDD+ activities be established in the RoS context to ensure uniform interpretation and monitoring moving forward. For instance, the definition of degradation used in this submission focuses primarily on reductions in canopy cover, but it may be useful to incorporate additional local factors to better capture the full scope of degradation.

Emission Factors: The emission factors and other parameters used in this submission have been derived from the published National Forest Inventory (2021), national literature, the IPCC guidelines and other regional and international sources. The NFI (2021) report provides good quality best available estimates based on ground measurements including standing volume, biomass, tree species, land use and biological diversity. However, there are gaps in the ground measurements due to the fact number of Sample Units (184 SUs) were not accessible during field work because of security and other reasons. As part of this national FRL project, the plan was to take measurements from the unvisited SUs, however, because of the current war situation this was not possible. RoS requested support from Maryland University through FAO to explore using GEDI data to gap-fill the NFI, missing sample-units (SUs). The report from this collaboration is expected to be included an addendum to the NFI report after being agreed by FNC relevant departments. The report includes new estimates of the volume and biomass covering also the areas of the SUs that are inaccessible. The results of this work, which is obtained through EO datasets are not replacing or recalibrating the NFI- estimated vegetation volume or biomass, there are simply serve as layers that augment, enhance, support and supplement the NFI estimates of vegetation volume or biomass.

Other REDD+ Activities: Inclusion of other significant REDD+ activities namely degradation still remain pending availability of the required data such as regular NFI measurements, high quality data on wood demand and consumption, etc. RoS intends to undertake further work to include forest degradation in future updates of its national FREL/FRL. The currently collaboration with Maryland University, mentioned above is exploring possibilities of developing data suitable for estimating emissions from forest degradation. The other REDD+ activities of conservation and sustainable management (SFM) of forests are currently not a priority for RoS, however, could be considered in future submission when good quality data become available for estimating emissions associated with their implementation.

Deadwood: The estimation of the amount of dead wood in RoS is difficult, because significant amount of deadwood is collected directly by local communities living in the proximity of the forests to meet their immediate energy demands. The Forest Product Demand Study (1995), estimated the amount of wood fuel directly collected by communities at about 72% of total fuelwood used in RoS and this is not captured in available records. The NFI (2021), provides estimates of carbon stock of deadwood including standing, fallen and stumps. These estimates are considered the first data on the carbon stock of dead wood remaining in the forests. However, RoS still does have the detailed data required by the 2006 IPCC Guidelines, such as data on the average annual transfer of carbon stock into and out of dead wood pools and data for the calculation of the difference between the dead wood carbon stock in two points in time. In this submission RoS includes only volume estimates of standing deadwood in the emission factor for deforestation, data on volume of standing deadwood considered by the NFI field experts as more reliable. Inclusion of dead wood remain an area for improvement in future updates when the require data become available. One of the recommendations in the NFI (2021) report states that future inventories should include data on forest soil carbon, litter and dead wood estimations.

Inclusion of forest Fires: The only important disturbance in RoS is fires, however, according to NFI 2021, in most of the forest area in RoS there is no evidence of fire, only about 3.63% of the total forest area experienced burning. The most common type of fires is the surface fire, which represent about 92.1% of the burnt area, while crown fire represents only about 0.18%) and the rest (about 7%) is underground fire. According to the national fire management strategy framework (2021), fires in RoS are human induced (not natural fires) and are mostly surface fires, which burns surface litter, other loose debris and small vegetation and usually cause least damage to forests. The forest burnt areas are insignificant compared to the total burnt areas in country. This might be attributed to high incidences of fire outbreak in dense grass area (savannah woodland) rather than forestland. Most of forest burn areas were found in Blue Nile, South Kordofan and South Darfur States. Also, most of the fires occurs on natural forest and very rarely on A/R and plantation forests, which are usually managed and better protected by fire lines. Good quality regular data on fires monitoring is needed for the inclusion of emissions from fires in the national FREL/FRL, currently such data is not available and therefore inclusion of emissions from forest fires remain and an area for improvement in future updates.

15. REFERENCES

Irrigated Forest Plantations in the Sudan: Case Study Gezira Agricultural Scheme
By Talaat D. A.Magi file:///Users/nagmeldin/Downloads/IrrigatedforsetplantationintheSudan.pdf

Alkaline pulping of some eucalypts from Sudan, P. Khristova [a], O. Kordsachia [b], R. Patt [b], S. Dafaalla (2006): https://www.sciencedirect.com/science/article/abs/pii/S0960852405002105

Effect of Growth Rate on Wood Density of Eucalyptus Camaldulensis Wood of Coppice Origin Grown in White Nile State Sudan, Ma Malik A. Y. Abdelgadir: https://www.semanticscholar.org/paper/Effect-of-Growth-Rate-on-Wood-Density-of-Eucalyptus-Malik-Abdelgadir/e86919792ed7bdb4f73aeecd39afaf20e958dde8

Sudan's Forest National Corporation (2021) National Forest Inventory Final Report:
https://www.fao.org/fileadmin/user_upload/faoweb/Themes__pages/Forests/REDD-NFM/Sudan_MRV/Sudan_-_NFI_Report.pdf
https://openknowledge.fao.org/server/api/core/bitstreams/9d8fe4c5-b3c5-45c0-9cac-07c5b64d4c0c/content

Sudan's REDD Programme (2018), In-depth Analysis of Drivers of Deforestation & Forest/Range Degradation

Sudan (2021), Fire Management Strategy Framework

Sudan's Forest National Corporation (2021), The National REDD+ Strategy and Action Plan

GFOI (2020), Integration of remote-sensing and ground-based observations for estimation of emissions and removals of greenhouse gases in forests. Methods and Guidance from the Global Forest Observations Initiative

HCENR (2021), Sudan's updated Nationally Determined Contribution

Cochran, W. G. (1977) Sampling techniques. John Wiley & Sons.

FAO. 2016. Map Accuracy Assessment and Area Estimation: A Practical Guide. National forest monitoring assessment working paper No.46/E, 60p.

Kozak, M. (2011) Comparison of efficiency of geometric stratification and k-means algorithm in Univariate stratification of skewed populations. Int. J. Agricult. Stat. Sci., Vol. 7, No. 1, pp. 341-344.

Neyman, J. (1934) On the Two Different Aspects of the Representative Method: The Method of Stratified Sampling and the Method of Purposive Selection. Journal of the Royal Statistical Society, Vol. 97, 558-606.

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.

IPCC (2006) Guidelines for National Greenhouse Gases Inventory

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

FAO (2020) Global Forest Resources Assessment Report, Sudan

FNC (2020), Forest Reference Level Submission to the UNFCCC

16. ANNEXES

Annex 1: Areas of the Afforestation and Reforestation of the 18 States of RoS

States	Northern		River Nile		Khartoum		Al-Gezira		Sinnar		White Nile	
Years	Seeds	Seedlings	Seeds	Seedlings	Seeds	Seedlings	Seeds	Seedlings	Seeds	Seedlings	Seeds	Seedlings
2012	748	5	1482	26	0	0	988	71	3802	105	1795	2683
2013	328	10	2990	39	3	1	1380	88	3297	423	68	81
2014	1134	19	1758	24	21	0	1723	42	1991	63	5371	128
2015	3066	42	2394	50	42	1	2318	4	4284	126	5932	186
2016	3677	34	2423	5	0	0	8132	15	6003	77	3738	1386
2017	2730	40	2423	5	0	0	0	0	4890	8	2415	0
2018	4626	14	794	0	0	0	643	0	2277	22	4049	12
2019	2310	13	852	0	25	0	0	150	4279	46	3048	67
2020	774	5	6	1785	0	0	654	42	215	0	4780	0
2021	363	12	2901	168	0	50	0	0	1927	383	5359	0
[redacted]												

States	Blue Nile		Gadarif		Kassala		Red Sea		North Kordofan		South Kordofan	
Years	Seeds	Seedlings	Seeds	Seedlings	Seeds	Seedlings	Seeds	Seedlings	Seeds	Seedlings	Seeds	Seedlings
2012	258	5	5579	0	0	1316	1776	5	9735	579	9735	579
2013	1782	6	3726	8	525	273	865	5	7652	1826	7652	1826
2014	1971	5	3365	0	739	368	1791	5	36023	3986	12230	1856
2015	1470	0	2100	2100	672	294	1890	4	28728	6258	10752	2100
2016	980	5	9813	0	824	303	1680	0	85877	8666	11206	1698
2017	4205	1	13167	0	815	235	764	3	66734	1058	12961	1539
2018	1965	2	8307	0	1428	386	1448	2	96369	4434	20287	1940
2019	221	1	8274	0	1806	271	708	2	36189	0	24931	549
2020	164	3	4950	27	0	25	1134	0	55541	0	27260	1223
2021	229	0	10960	16	2058	420	630	1	93996	0	5262	1003
[redacted]												

States	W. Kordofan		N. Darfour		S. Darfour		E. Darfour		W. Darfour		C. Darfour	
Years	Seeds	Seedlings	Seeds	Seedlings	Seeds	Seedlings	Seeds	Seedlings	Seeds	Seedlings	Seeds	Seedlings
2012	9735	579	1391	780	1733	394	382	265	762	913	630	46
2013	7652	1826	820	987	4000	346	777	336	2410	825	686	44
2014	8736	375	3488	1045	2294	212	1386	252	4683	335	941	168
2015	12306	1638	1512	1176	1680	252	8	42	1344	126	966	126
2016	17720	1197	4190	902	5675	323	5683	424	2872	35	903	240

2017	22680	1232	3700	888	10605	908	5880	588	1092	92	3045	258
2018	51054	2560	7136	1010	11804	376	12733	0	8679	135	2384	289
2019	55101	3262	6045	1629	3570	214	1680	2	7140	630	3276	297
2020	71192	3476	2401	1268	2662	861	1772	252	8190	449	1567	1884
2021	65252	7103	3140	1394	5040	294	4263	0	9240	890	4233	6182
[redacted]												

Annex 2: Wood Density data

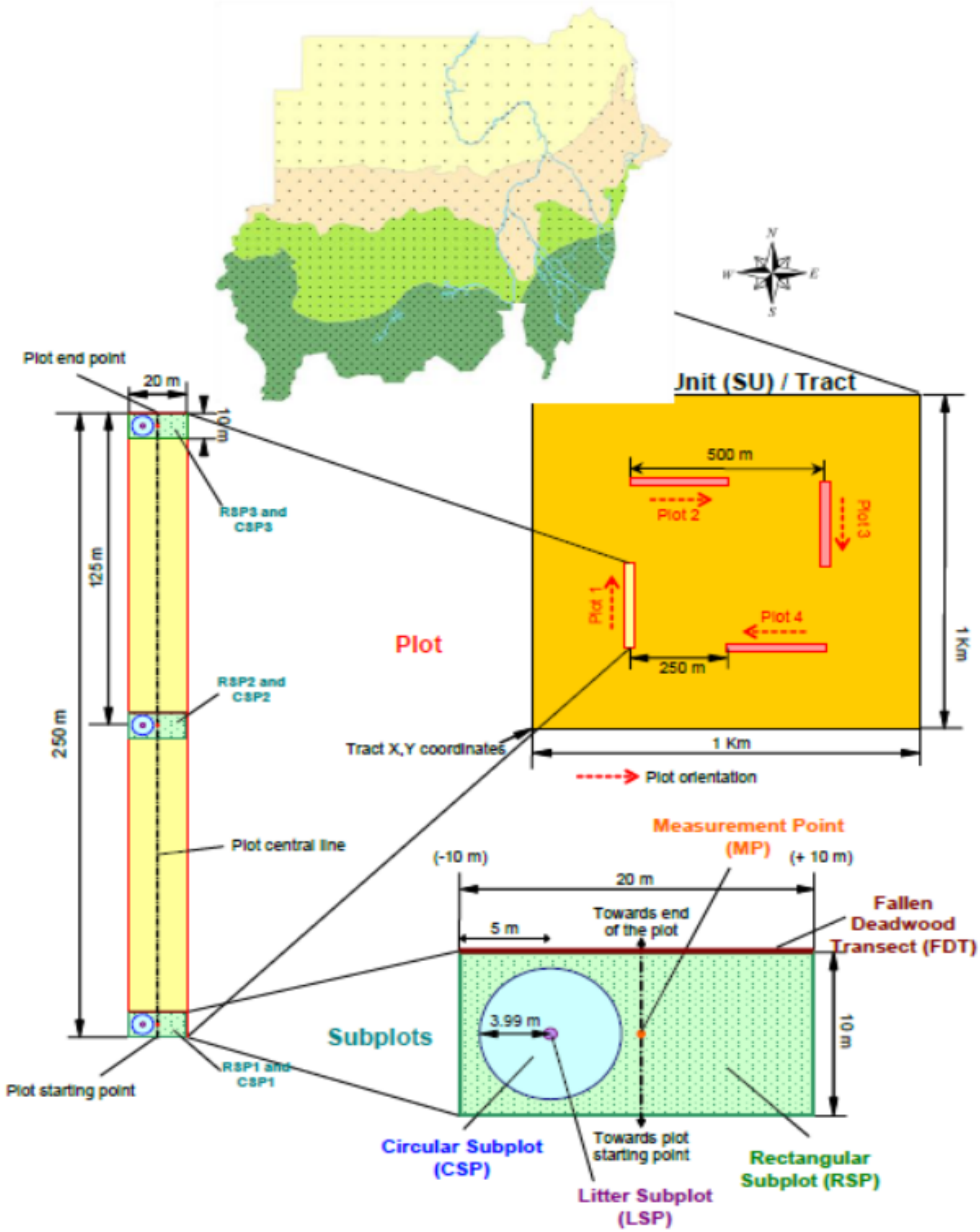
Species	WD t. d.m/m^3	Source
Acacia tortilis f. raddiana	0.44	FNC 2019, Integrated Carbon Sequestration Project Establishment of Biomass Carbon Baseline
Acacia Seyal	0.7	Tarig O. Khider and Osman T. Elsaki, 2012. Heat Value of Four Hardwood Species from Sudan, JOURNAL OF FOREST PRODUCTS & INDUSTRIES, 2012, 1(2), 5-9
Acacia Senegal	0.7	Tarig O. Khider and Osman T. Elsaki, 2012. Heat Value of Four Hardwood Species from Sudan, JOURNAL OF FOREST PRODUCTS & INDUSTRIES, 2012, 1(2), 5-9
Acacia Mellifera	0.7	Tarig O. Khider and Osman T. Elsaki, 2012. Heat Value of Four Hardwood Species from Sudan, JOURNAL OF FOREST PRODUCTS & INDUSTRIES, 2012, 1(2), 5-9
Acacia Nilotica	0.8	M. A. Elfdl, 1985. Biomass estimation and energy content of acacia nilotica in the Blue Nile Master thesis , University of Khratoum
Eucalyptus Spp	0.4 -0.7	Alkaline pulping of some eucalypts from Sudan, P. Khristova [a], O. Kordsachia [b], R. Patt [b], S. Dafaalla (2006): https://www.sciencedirect.com/science/article/abs/pii/S0960852405002105
E. Camaldulensis	0.7	Effect of Growth Rate on Wood Density of Eucalyptus Camaldulensis Wood of Coppice Origin Grown in White Nile State Sudan, Ma Malik A. Y. Abdelgadir: https://www.semanticscholar.org/paper/Effect-of-Growth-Rate-on-Wood-Density-of-Eucalyptus-Malik-Abdelgadir/e86919792ed7bdb4f73aeecd39afaf20e958dde8
Khaya Senegalensis	0.6 - 0.85	Agroforestry Database 4.0 (Orwa et al.2009) https://apps.worldagroforestry.org/treedb/AFTPDFS/Khaya_senegalensis.PDF
Dalbergia sissoo	0.62 -0.82	Agroforestree Database

		A tree reference and selection guide. Version 4.0. https://apps.worldagroforestry.org/treedb2/speciesprofile.php?Spid=645
Acacia polyacantha	0.81 – 0.9	World Agroforestry Center: African Wood Density Database Carsan S, Orwa C, Harwood C, Kindt R, Stroebel A, Neufeldt H, and Jamnadass R. 2012. African Wood Density Database. World Agroforestry Centre, Nairobi. https://apps.worldagroforestry.org/treesnmarkets/wood/data.php#
Acacia sieberana	0.65 -0.72	"World Agroforestry Center: African Wood Density Database
Albizia aylmeri	0.73 -0.8	"
Anogeissus leiocarpus	0..91 – 1.04	"
Azadirachta indica	0.65 – 0.9	"
Cupressus lusitanica	0.38 – 0.65	"
Dalbergia melanoxylon	1.23 – 1.33	"
Sclerocarya birrea	0.51-0.64	"
Boswellia papyrifera	0.720	Robert Nygård*and Björn Elfving (1999), Stem basic density and bark proportion of 45 woody species in young savanna coppice forests in Burkina Faso. https://hal.archives-ouvertes.fr/hal-00883170/document.
Dalbergia melanoxylon	0.817	Robert Nygård*and Björn Elfving (1999), Stem basic density and bark proportion of 45 woody species in young savanna coppice forests in Burkina Faso. https://hal.archives-ouvertes.fr/hal-00883170/document.
Albizia Amara	0.7	FAO: Appendix 1 - List of wood densities for tree species from tropical America, Africa, and Asia. http://www.fao.org/3/w4095e/w4095e0c.htm Also in the IPCC 2006, chapter 4 table 4.13
Anogeissus leiocarpus	0.73	Ogunwusi, A.A. and Onwualu,A.P and 2Ogunsanwo, O.Y (2013) Comparative Analysis of Wood Properties of Afzelia africana and Anogeissus leiocarpus Growing in Nigeria. Chemistry and Materials Research www.iiste.org ISSN 2224- 3224 (Print) ISSN 2225- 0956 (Online) Vol.3 No.3, 2013
Balanites aegyptiaca	0.63	IPCC 2006, Chapter 4, table 4.13
Albizia amara	0.70	IPCC 2006, Chapter 4, table 4.13
Tamarindus indica	0.81-1.14	https://apps.worldagroforestry.org/treesnmarkets/wood/data.php#
Acacia gerrardii var. gerrardii	0.9	https://prota.prota4u.org/protav8.asp?g=pe&p=Acacia+gerrardii
Boswellia serrata	0.5	https://www.fao.org/4/w4095e/w4095e0c.htm
Terminalia macroptera	0.81-0.9	https://apps.worldagroforestry.org/treesnmarkets/wood/data.php#
Sterculia Spp	0.55	Gisel Reyes, Sandra Brown, Jonathan Chapman, and Ariel E. Lugo (1992) Wood Density of Tropical Tree Species
Adansonia digitata	0.3	https://apps.worldagroforestry.org/treedb/AFTPDFS/Adansonia_digitata.PDF

Terminalia spp	0.50, 0.51, 0.58 +	https://www.fao.org/4/w4095e/w4095e0c.htm
Dalbergia melanoxylon	1.23 -1.33	https://apps.worldagroforestry.org/treesnmarkets/wood/data.php#
Combretum ghasalense	0.845	http://db.worldagroforestry.org//wd/species
Terminalia brownii	0.654	Ethiopia FRL submission to the UNFCCC : Average of genus (http://db.worldagroforestry.org//wd/genus/Terminalia)
Boswellia papyrifera	0.500	Ethiopia FRL submission to the UNFCCC
Sterculia setigera	0.320	Ethiopia FRL submission to the UNFCCC : http://db.worldagroforestry.org//wd/species/Schefflera_abyssinica
Bauhinia spp.	0.67	FAO Data: https://www.fao.org/4/w4095e/w4095e0c.htm
Ficus sp.	0.32	"
Diospyros spp	0.82	"
Celtis spp.	0.59	"
Ziziphus mauritiana	535-1080 kg/m³	https://apps.worldagroforestry.org/treedb/AFTPDFS/Ziziphus_mauritiana.PDF
Prosopis africana	0.91-1.04	https://apps.worldagroforestry.org/treesnmarkets/wood/data.php#
Terminalia macroptera	0.81- 0.90	"
Pseudocedrela kotschyi	0.73- 0.80	"
Combretum aculeatum	0.474	Ethiopia FRL submission to the UNFCCC : http://db.worldagroforestry.org//wd/species/Schefflera_abyssinica
Commiphora africana	0.48	"
Ficus sycomorus	0.422- 0482	"
Acacia drepanolobium	0.769	"
Diospyros mespiliformis	0.85	https://apps.worldagroforestry.org/treedb/AFTPDFS/Diospyros_mespiliformis.PDF
Prosopis africana	0.91-1.04	https://apps.worldagroforestry.org/treesnmarkets/wood/data.php#
Lannea fruticosa	0.515	Ethiopia FRL submission to the UNFCCC : http://db.worldagroforestry.org//wd/species/Schefflera_abyssinica
Stereospermum kunthianum	0.74	"
Pterocarpus lucens	0.7-0.8	https://apps.worldagroforestry.org/treesnmarkets/wood/data.php#
Lannea schimperi	0.515	Ethiopia FRL submission to the UNFCCC : http://db.worldagroforestry.org//wd/species/Schefflera_abyssinica

Commiphora Sp	0.389	“
Combretum glutinosum	0.9	GlobalWoodDensityDatabase.
Combretum hartmannianum	0.791	Average value for Combretum Sp: GlobalWoodDensityDatabase
Combretum gallabatense	“	“
Combretum paniculatum	“	“
Combretum lamprocarpum	“	“
Commiphora quadricincta	0.381	Average value for Commiphora Sp: GlobalWoodDensityDatabase
Capparis spinosa	0.691	Average value for Capparis Sp: GlobalWoodDensityDatabase
Guiera senegalensis	0.690	John Charles Weber et.al (2018), Variation in growth, wood density and carbon concentration in five tree and shrub species in Niger: https://www.researchgate.net/publication/318379324_Variation_in_growth_wood_density_and_carbon_concentration_in_five_tree_and_shrub_species_in_Niger
Acacia laeta	0.7	Average value of Acacia species in RoS
Lannea schweinfurthii	0.551	GlobalWoodDensityDatabase.
Maerua pseudopetalosa	0.58	Average of tropical Africa: Ethiopia FRL submission to the UNFCCC : http://db.worldagroforestry.org//wd/species/Scheffl era_abyssinica
Albizia anthelmintica Albizia spp.	0.52	https://www.fao.org/4/w4095e/w4095e0c.htm
Bauhinia rubescens	0.808	Average value for Bauhinia sp: GlobalWoodDensityDatabase.
Dobera glabra	0.67 - 0.71	World Agroforestry Centre | agroforestree database 4.0
Cordia abyssinica Cordia Sp	0.53	https://www.fao.org/4/w4095e/w4095e0c.htm
Acacia drepanolobium	0.7	Average value of Acacia species in Sudan
Mitragyna inermis	0.528	Average value for Mitragyna sp: GlobalWoodDensityDatabase.
Borassus aethiopum	1.02 -1.14	https://apps.worldagroforestry.org/treesnmarkets/wood/data.php#

Annex 3: Sampling unit, plot and subplot design



Annex 4: Calculation Procedures Used in the RoS NFI

Introduction

This document details the main calculation procedures implemented in the National Forestry Inventory (NFI), especially regarding the allometric equations used to calculate derived variables such as volume, biomass, and carbon. The calculation procedures are stored as SQL instructions in the NFI database and can be executed using Silva Metricus software.

The calculation procedures described below are stored in the table named sibp_calculationfields in the NFI database; this table is used by Silva Metricus software to perform calculations defined by the user and to store the results in the corresponding fields. The calculation procedures have a sequential order that allows using calculations based on other calculations; for example, to calculate volume per hectare, the number of trees per hectare must first be calculated to multiply this value by the volume of an individual tree. The table sibp_calculationfields has the following fields:

Table : Fields of the table for storing descriptions of calculations

No.	Field	Type and length	Description
1	configurationnumber	Numeric	Configuration number of NFI
2	tablename	Short text	Name of the table containing the field to be calculated
3	fieldname	Short text	Name of the field to be calculated
4	presentationorder	Numeric	Calculation order
5	fieldname_p	Short text	Descriptive name of the field to be calculated in the primary language
6	fieldname_s	Short text	Descriptive name of the field to be calculated in the secondary language (not used in the case of the NFI of Sudan)
7	fielddescription_p	Short text	Broader description of the field to be calculated, which is done in the primary language.
8	fielddescription_s	Short text	Description or more extensive explanation of the field to be calculated, which is in the secondary language. (not used in the case of the NFI of Sudan)
9	fieldunits	Short text	Units of measurement for the corresponding calculation.
10	fieldtype	Short text	Type of field (text, number, list, etc.)
11	fieldlength	Numeric	Total length of the field
12	decimalsnumber	Numeric	Number of decimals to be used, in case it is a field of double precision.
13	fieldformat	Short text	Field display format; formed by the field length and the number of decimals.

No.	Field	Type and length	Description
14	useforcalculations	Logical	A field used to define whether the variable will be used in regression calculations (yes/no)
15	tablenameoldversion	Short text	Name of the table that contained the field in previous versions of SIBP2 (previous version of Silva Metricus)
16	fieldnameoldversion	Short text	Name of the field in previous versions of SIBP2.
17	calculationtype	Short text	Type of calculation: special or SQL; special is a type of calculation that is already predefined in Silva Metricus and SQL is a calculation that uses an expression in SQL language.
18	sqlexpression	Short text	SQL expression for the calculation.
19	specialexpression	Short text	Type of predefined calculation
20	specialtable	Short text	Special table associated with a predefined calculation
21	specialfield	Short text	Special field associated with the predefined calculation.
22	representdbh	Short text	Variable representing DBH in the predefined calculation.
23	representtotalheight	Short text	Variable representing total height in the predefined calculation.
24	representcommheight	Short text	Variable representing the commercial height or bole height in the predefined calculation.

Below, the calculations performed to estimate trees per hectare, basal area, volumes, biomass, and carbon for individual trees are described in detail.

Tree-level Calculations

Below a description of the calculations for the tree table (aa_tree) is detailed, most of the calculations make use of SQL instructions and are stored in the database so that they can be used in the variable calculation module of Silva Metricus.

Trees per hectare

In the design of the forest inventory, sampling units of 4 rectangular plots of 20m x 250m are used in which all trees 20 centimeters or greater in DBH are measured; also, there are three nested plots (by SU) of 10m x 20m where trees with DBH between 10 and 19.9 centimeters are measured. Depending on the case, the trees have different hectare expansion factors, below are the expansion factors according to the DBH of the tree:

- DBH≥10 cm and DBH<20 cm: the total area of a plot where these trees are measured is 200 m^2, so in a sampling unit this type of trees is measured in an area of 2400 m^2 (200 m^2 x 12); therefore, the expansion factor is 10000/2400 =4.1667. This means that each tree of the indicated category represents 4.1667 trees per hectare.

- DBH≥20 cm: the total area of a plot where these trees are measured is 5000 m^2, therefore, in a sampling unit this type of trees is measured in an area of 20000 m^2 (5000 m^2 x 4); in this case the expansion factor is 10000/20000=0.5. This means that each tree of the indicated category represents 0.5 trees per hectare.

At the database level, the number of trees per hectare that each of the measured trees represents is stored in the field tre_treesperhectare of the table aa_tree, it is a double number type of field, and the calculation corresponds to the following SQL instruction:

UPDATE aa_tree SET aa_tree.tre_treesperhectare = IIf([aa_tree].[tre_dbh]>=20, 0.5, IIf([aa_tree].[tre_axisdistance]<=10 Or [aa_tree].[tre_axisdistance]>=240 Or ([aa_tree].[tre_axisdistance]>=120 And [aa_tree].[tre_axisdistance]<=130), 4.1667, 0.5))

Basal area

The basal area per hectare represented by each of the trees measured in the field is calculated using the formula:

$$G = \left({}^{DBH}/_{100}\right)^2 * 0.7854 * N$$

Where:
G=basal area in m^2/ha
DBH=Chest Height Diameter or Reference Diameter in centimeters
N=Number of trees per hectare (calculated in the previous section)

The SQL instruction executed by Silva Metricus is as follows:

UPDATE aa_tree SET aa_tree.tre_basalareaha = Round(([aa_tree].[tre_dbh]/100)^2*0.7854*[aa_tree].[tre_treesperhectare],6)

Estimated total and commercial height

In the case of the NFI, it is not necessary to calculate the total and commercial height using regression models, as the heights are measured or estimated directly in the field for all trees.

Total and commercial tree volume

For the calculation of the total volume[3] that each of the trees represents per hectare, a formula with a form factor of 0.6 is used and the volume of thick branches is added, the formula is as follows:

Vt=G*th*0.6 + Vb

[3] It refers mainly to the volume of the trunk and large branches, excluding the stump.

Where:

Vt=Volume of the tree in m^3/ha
G=basal area per hectare represented by the tree in m^2/ha
th=Total height of the tree in meters
Vb= is the volume of the thickest branches, for the calculation the Smalian formula is used which is the average of the basal areas of the smaller and larger diameter multiplied by the length of the branch.

The field where the total bole volume in cubic meters per hectare is stored is tre_totalvolumeha, it is of double type and the calculation is made with 6 decimal places. The SQL instruction for the calculation is as follows:

Branch volume:

```
UPDATE aa_tree SET aa_tree.tre_branchesvolumeha
=IIF(Round((IIF([aa_tree].[tre_branch1diameter]>0,([aa_tree].[tre_branch1diameter]/100)^2*0.7
854*[aa_tree].[tre_branch1length],0) +
IIF([aa_tree].[tre_branch2diameter]>0,([aa_tree].[tre_branch2diameter]/100)^2*
0.7854*[aa_tree].[tre_branch2length],0) +
IIF([aa_tree].[tre_branch3diameter]>0,([aa_tree].[tre_branch3diameter]/100)^2*
0.7854*[aa_tree].[tre_branch3length],0) +
IIF([aa_tree].[tre_branch4diameter]>0,([aa_tree].[tre_branch4diameter]/100)^2*
0.7854*[aa_tree].[tre_branch4length],0))*[aa_tree].[tre_treesperhectare],6)>0,Round((IIF([aa_tr
ee].[tre_branch1diameter]>0,([aa_tree].[tre_branch1diameter]/100)^2*0.7854*[aa_tree].[tre_bra
nch1length],0) +
IIF([aa_tree].[tre_branch2diameter]>0,([aa_tree].[tre_branch2diameter]/100)^2*0.7854*[aa_tree
].[tre_branch2length],0) +
IIF([aa_tree].[tre_branch3diameter]>0,([aa_tree].[tre_branch3diameter]/100)^2*0.7854*
[aa_tree].[tre_branch3length],0) +
IIF([aa_tree].[tre_branch4diameter]>0,([aa_tree].[tre_branch4diameter]/100)^2*0.7854*
[aa_tree].[tre_branch4length],0))*[aa_tree].[tre_treesperhectare],6),0)
UPDATE aa_tree SET aa_tree.tre_volumeha =
Round(IIF(tre_boleheight>0,tre_basalareaha*tre_boleheight*0.56,
tre_basalareaha*(6.123*tre_dbh^0.442)*0.56),6)
```

Total volume:

```
UPDATE aa_tree SET aa_tree.tre_totalvolumeha =
Round([aa_tree].[tre_basalareaha]*[aa_tree].[tre_totalheight]*[aa_tree].[tre_formfactortv]+
IIF([aa_tree].[tre_branchesvolumeha]>0,[aa_tree].[tre_branchesvolumeha],0),6)
```

For the calculation of the volume of the bole per hectare represented by each of the trees, the form factor 0.6 is always used; however, in this case the height of the bole is used not the total height, the SQL instruction is as follows:

UPDATE aa_tree SET aa_tree.tre_bolevolumeha =
Round([aa_tree].[tre_basalareaha]*[aa_tree].[tre_boleheight]* [aa_tree].[tre_formfactorcv],6)

Aboveground biomass

To estimate the aerial biomass (AGB) of the trees, the following biomass model is used:

$AGB=0.0673*(\rho*DBH^2*th)^{0.976}/1000$, global equation developed by J. Chave et al.

Where:
AGB = aboveground biomass in megagrams per hectare [Mg/ha])
DBH = Diameter at Breast Height or reference diameter (cm)
th= total height in meters
ρ = wood density (g/cm^3)

To use this allometric equation of aboveground biomass, the value of the wood density for each species in the database is required, so for some species (example Acacia mellifera) the average wood density that was reported in national studies was used (associated in the database). For establishing the wood density of other species in the database, the DRYAD[4] database was used as a reference. From this database, only species from the Africa region were used. If the species does not have a reference for average density in the DRYAD database, the average of the genus is used; if there are no genus data, the average of the family is used; if none of the above is possible to obtain, the average of all species is used, corresponding to 0.6035 g/cm^3.

Before calculating the aboveground biomass, it is necessary to associate each of the trees with the wood density according to the species (field tre_wooddensity), said procedure is done using the following SQL instruction:

UPDATE cs_treespecies INNER JOIN aa_tree ON cs_treespecies.tsp_code = aa_tree.tre_specie
SET aa_tree.tre_wooddensity = Round([cs_treespecies].[tsp_wooddensity],4)

For calculating the aboveground biomass in tons per hectare, the field tre_biomassha is used and the SQL instruction is as follows:

UPDATE aa_tree SET aa_tree.tre_biomassha = Round((0.0673*([aa_tree].[tre_wooddensity]*
[aa_tree].[tre_dbh]^2*[aa_tree].[tre_totalheight])^0.976)/1000*[aa_tree].[tre_treesperhectare],6)

Underground Biomass

The underground biomass (roots) of trees is stored in the field tre_undergroundbiomass, which is a double precision field and uses megagrams per hectare as its units. The calculation of

[4] http://datadryad.org/repo/handle/10255/dryad.235

underground biomass uses the estimation of aboveground biomass as an independent variable, and the model by Cairns et al. (1997)[5] is applied for its calculation.

$$bgb = e^{[-1.0587+0.8836\cdot\ln(agb)]}$$

Where:
bgb = underground biomass (Mg/ha)
agb = aboveground biomass (Mg/ha)

Carbon and CO_2 Equivalent

Each species in the database is associated with a carbon percentage (47%), and this percentage is applied to each tree. The SQL statement for assigning the carbon percentage in the tree table is as follows:

```
UPDATE cs_treespecies INNER JOIN aa_tree ON cs_treespecies.tsp_code = aa_tree.tre_specie
SET aa_tree.tre_carbonpercentage =
IIF([cs_treespecies].[tsp_carbonpercentage]=Null,47,[cs_treespecies].[tsp_carbonpercentage])
```

To calculate the carbon amount, the biomass is multiplied by the carbon content (%). The amount of CO_2 equivalent is calculated by multiplying the carbon content by the constant 3.67. The following are the SQL instructions for calculating carbon and CO_2 equivalent:

Aboveground Carbon:

```
UPDATE aa_tree SET aa_tree.tre_carbonha = Round([aa_tree].[tre_biomassha]*
[aa_tree].[tre_carbonpercentage]/100,6)
```

Underground Carbon (roots):

```
UPDATE aa_tree SET aa_tree.tre_undergroundcarbon =
Round([aa_tree].[tre_undergroundbiomass]* [aa_tree].[tre_carbonpercentage]/100,6)
```

Aboveground CO_2:

```
UPDATE aa_tree SET aa_tree.tre_co2ha = Round([aa_tree].[tre_biomassha]*
[aa_tree].[tre_carbonpercentage]/100*3.67,6)
```

Underground CO_2 (roots):

[5] Cairns, M.A., Brown, S., Helmer, E.H. & Baumgardner, G.A. (1997). *Root biomass allocation in the world's upland forests*. Oecologia, 111(1): 1–11.

UPDATE aa_tree SET aa_tree.tre_underground = Round([aa_tree].[tre_underground biomass]*[aa_tree].[tre_carbon percentage]/100*3.67,6)

Associated Land Use Class (LULC)

To do estimates by type of LULC (at various levels) using the "ratio estimators" technique, it is necessary to associate each tree with the LULC in which it is located. The SQL instruction to assign the LULC point associated with each tree of the plot is as follows:

UPDATE aa_lucs INNER JOIN aa_tree ON (aa_lucs.luc_lucsnumber = aa_tree.tre_luccnumber) AND (aa_lucs.luc_plotnumber = aa_tree.tre_plotnumber) AND (aa_lucs.luc_tractnumber = aa_tree.tre_tractnumber) AND (aa_lucs.luc_measurementnumber = aa_tree.tre_measurementnumber) AND (aa_lucs.luc_inventorynumber = aa_tree.tre_inventorynumber) SET aa_tree.tre_lucscode = [aa_lucs].[luc_lucc]

LULC Code and Other Classification Levels

Once the LULC number has been assigned to each tree, it is necessary to associate the corresponding LULC code, to perform calculations at the level of LULC and other land use or land cover classification systems. This assignment uses the table aa_landusesubplot and the following SQL instruction:

UPDATE cc_landuselevel3 INNER JOIN aa_tree ON cc_landuselevel3.code = aa_tree.tre_lucscode SET aa_tree.tre_luclevel0 = [cc_landuselevel3].[luclevel0], aa_tree.tre_luclevel1 = [cc_landuselevel3].[luclevel1], aa_tree.tre_luclevel2 = [cc_landuselevel3].[luclevel2]

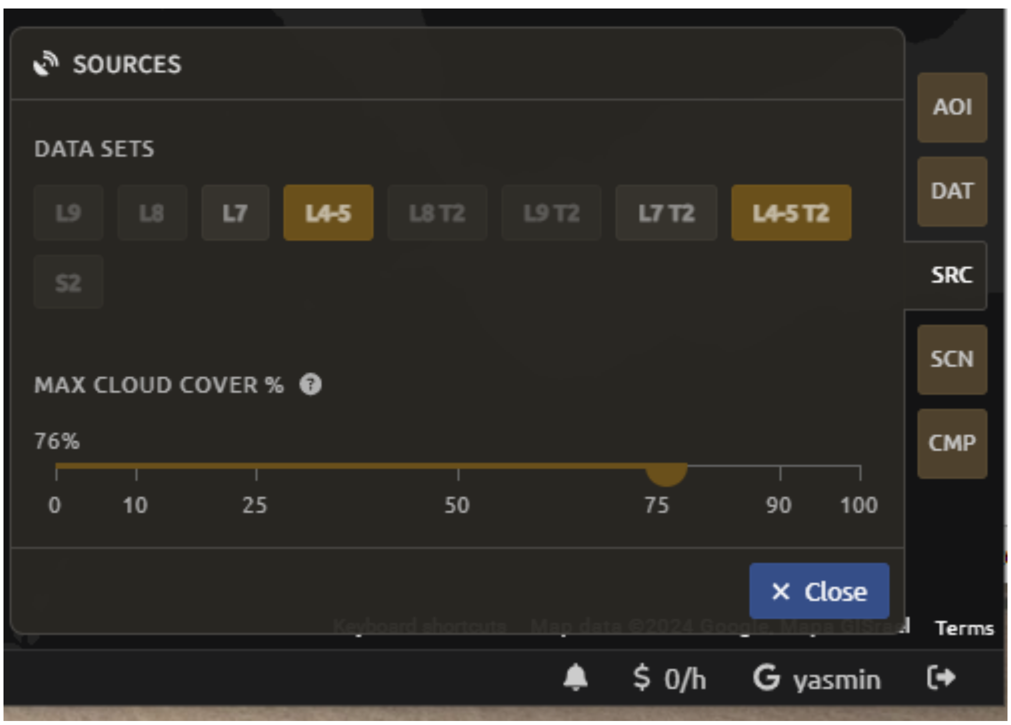
Annex 5: List of Assets used for Activity Data

Sr. No.	Monitoring Year	Name of Asset	Asset Id
1	**Time-2 (2023)**	Landsat 2023	projects/ee-abdallatana/assets/LANDSAT_MOCIC_2023/RoS_FREL_Mosiac_landsat_2023_Project
2		Landsat 2024	projects/ee-moelmardi80/assets/Landsat8_Mosaic_RoS2024
3		Planet NICFI 2023	projects/ee-fardaadmad88/assets/RoS_FREL_Mosiac_landsat_2023_Project/RoS_planet_2023_30m
4		Planet NICFI 2024	projects/ee-fardaadmad88/assets/RoS_FREL_Mosiac_landsat_2023_Project/RoS_planet_2024_30m
5		ALOS 2023	projects/ee-nailayasmin-RoS/assets/ALOS_KandC2023_RoS
6	**Time -1 (2011)**	Landsat 2011	projects/ee-nailayasmin-RoS/assets/RoS_2011_2009_L457
7		ALOS 2010	projects/ee-nailayasmin-RoS/assets/ALOS_KandC2010_RoS
8	**Training Data FNF (2010 – 2023)**		projects/ee-nailayasmin-RoS/assets/ceo-Sdn_2020_LC_training_data-plot-data-2024-09-24_byjalal_edited
9	**RoS NFI Systematic grid (full population)**		projects/ee-nailayasmin-RoS/assets/RoS_NFI_grid_noduplicates

Annex 6: Annual Composite of Landsat Year 2011

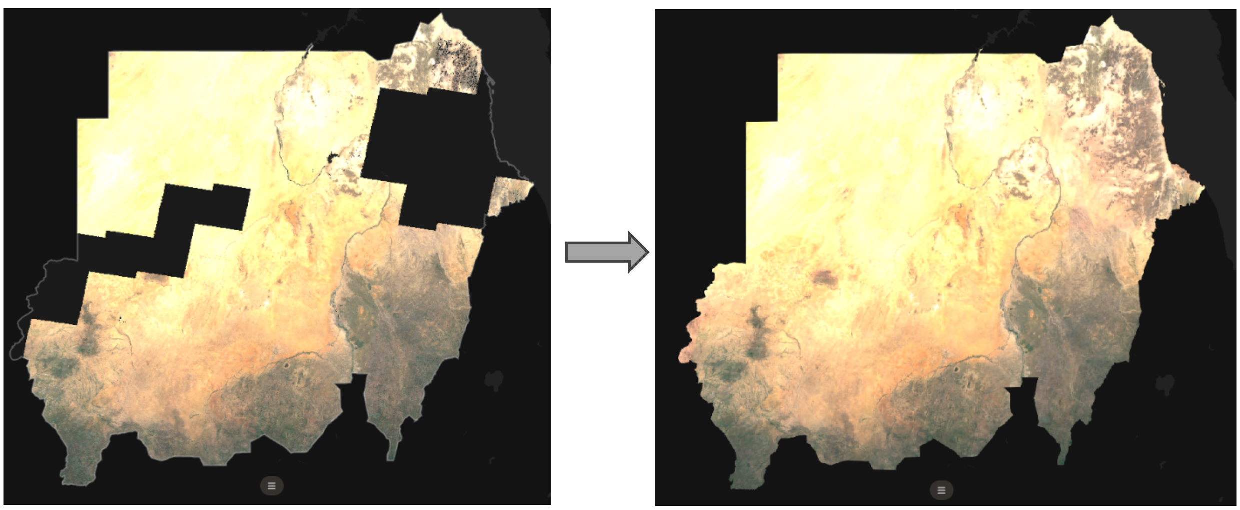
1. In order to create an annual composite of 2011, Optical mosaic recipe in SEPAL was used.
2. For AOI selection National customized boundary was used and uploaded as an asset in GEE, asset is id is listed in Table-1.
3. Date range was extended beyond the 2011 as of insufficient data, as shown in screenshot below; season here defined as a full calendar year, so in this case date range used for composite is 2009-2011

4. The scene from only Landsat 4-5 are used to get a better quality composites for classification, comprises of both Tier-1 and Tier-2 collection



5. The pre-processing parameters are used are highlighted in below given screenshot

6. Missing pixels were filled using pixels from Landsat-7 collection



7. And finally, image composite was exported as an asset

Annex 7: Supporting aboveground biomass and volume estimation with Earth Observation

Authored by:
Neha Hunka (University of Maryland; nhunka@umd.edu),
Paul May (South Dakota School of Mines and Technology),
Chad Babcock (University of Minnesota)

Date: December 2024

Introduction

Sudan's National Forest Inventory (NFI) provides estimates needed for vegetation and forest assessments of the country, including volume and aboveground biomass density (AGBD). The sampling design of the Sudanese NFI is a systematic grid, with its density varying by ecological strata across the extent of the country. Spatial gaps in the NFI, however, are present due to the inaccessibility of some areas of the country. These spatial gaps from unvisited plots result in a violation the proposed sampling design of the NFI, thereby challenging strata-wise, state-level or any area- wide assessments in the country. Visited and measured NFI plots are displayed in Figure 1a.

To overcome this challenge, Earth Observation (EO) datasets are used to provide supplementary information in support of the ground-based inventory. In a model- based framework, for example, use of auxiliary information from EO datasets can allow spatial scaling of the NFI estimates, thereby filling gaps where NFI plots were not visited, allowing area-wide estimations of aboveground biomass or volume and improving their precision (e.g., Babcock et al., 2018; Breidenbach et al., 2021; Emick et al., 2023; May et al., 2023). Important to note is that, in the case of Sudan, EO datasets are not replacing or recalibrating (or thereby biasing in any way) the NFI-estimated vegetation volume or biomass. The EO datasets simply serve as layers that augment, enhance, support and supplement the NFI estimates of vegetation volume or biomass. Hence, irrespective of the pixel-level accuracies of the supportive EO map layers, they can be modeled to augment the NFI as long as they capture spatial variations across the domain of the country. The other important considerations for the use of auxiliary EO datasets to enhance the NFI are (1) the visited NFI plots provide a fair representation of the range of vegetation volume and AGBD found over the extent of Sudan, and (2) the auxiliary EO datasets are acquired or created independent of the NFI data.

For the case of Sudan, estimates of vegetation aboveground biomass from the NASA Global Ecosystem Dynamics Investigation (NASA GEDI) (Dubayah et al., 2020)

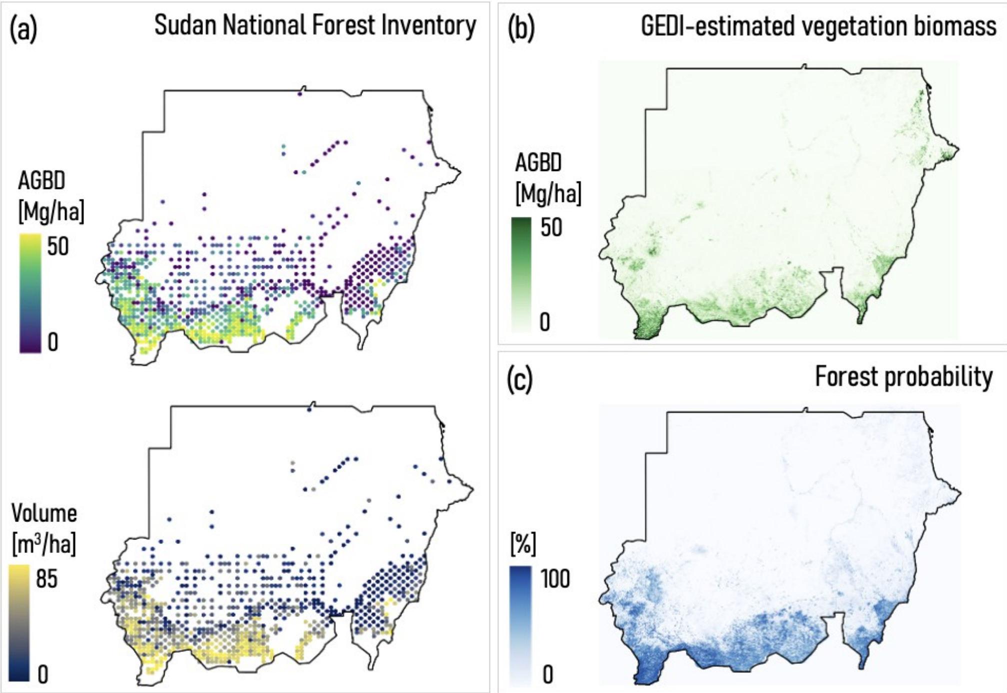


Figure 1: NFI estimates of aboveground biomass and volume, and the covariates used in the geo- statistical model. The covariates are NASA GEDI-estimated aboveground biomass and the Forest Non-Forest (FNF) Probability Map 2023 over Sudan.

and the Forest Non-Forest (FNF) Probability Map 2023 are used as auxiliary EO data sources. The former dataset, i.e. the NASA GEDI data, is available as 25-m footprints of aboveground biomass estimated from high resolution laser-measured vegetation height, collected between years 2019-2023 (Dubayah et al., 2021). These footprint-level AGBD estimates are based on generic global models (Duncanson et al., 2022), and their accuracy over Sudan is hitherto unknown. However, note again, we are interested in only using this GEDI data to augment the NFI, hence calibrating it to the NFI-estimated AGBD, irrespective of its footprint-level accuracy. The GEDI footprint-level AGBD estimates are averaged in a 1 km × 1 km grid across Sudan, making a near-continuous map of estimates (Figure 1b). The latter dataset, i.e., Forest Non-Forest (FNF) Probability Map 2023 (Figure 1c), is described previously in sections of Activity Data for Sudan.

Methodology

Geostatistical model relating EO and NFI data

The method adopted for Sudan is based on the geostatistical approach provided in Hunka et al. (2025). This section provides a brief overview of the approach, as well as the link to access to the open-source R code released to run the model for the case of Sudan.

A geostatistical model-based approach is used to relate the Sudanese NFI to the auxiliary EO datasets, with inference conducted through Bayesian methods. A geo- statistical model is effective in capturing spatially continuous variables (here, AGBD or volume) that have been measured only at a finite number of sites (here, the visited NFI locations). The model itself is a linear regression, relating the NFI-estimated aboveground biomass or volume to the EO datasets' values at the locations of the NFI plots. EO dataset values are extracted as the mean value of EO map pixels that intersect an NFI plot cluster (of size 500 m × 500 m), weighted by the fraction of the pixel that is covered by the cluster (see 'exactextractr' package in 'R'). In the linear regression, however, we further add a geostatistical component, such that components of the model parameters are allowed to vary across the domain of Sudan. Adding such components allows to account for spatial variation in the regression coefficients and spatial autocorrelation in the model residuals (May et al., 2023; Emick et al., 2023; Hunka et al., 2025). We assume the model

$$y(\boldsymbol{s}) = \Big(\alpha + \tilde{\alpha}(\boldsymbol{s})\Big) + \Big(\beta + \tilde{\beta}(\boldsymbol{s})\Big)x_1(\boldsymbol{s}) + \Big(\eta + \tilde{\eta}(\boldsymbol{s})\Big)x_2(\boldsymbol{s}) + \epsilon(\boldsymbol{s}), \qquad (1)$$

where

$\boldsymbol{s}$ is a two-dimensional coordinate vector defining a spatial location

$y(\boldsymbol{s})$ is the NFI-estimated volume or AGBD at location $\boldsymbol{s}$

$x_1(\boldsymbol{s})$ is the GEDI estimate of vegetation biomass at location $\boldsymbol{s}$

$x_2(\boldsymbol{s})$ is the forest probability value at location $\boldsymbol{s}$

α is the intercept

β is a model parameter

η is a model parameter

$\tilde{\alpha}(\boldsymbol{s})$ is the spatially-varying component of intercept α at location $\boldsymbol{s}$

$\tilde{\beta}(\boldsymbol{s})$ is the spatially-varying component of parameter β at location $\boldsymbol{s}$

$\tilde{\eta}(\boldsymbol{s})$ is the spatially-varying component of parameter η at location $\boldsymbol{s}$

The spatially varying parameters ($\tilde{\alpha}(\boldsymbol{s})$, $\tilde{\beta}(\boldsymbol{s})$ and $\tilde{\eta}(\boldsymbol{s})$) are assumed to follow mean-zero *Gaussian processes* (Gelfand and Schliep, 2016). A covariance function, defining covariance between two points to decay near-exponentially as the distance between them increases, was used to dictate the spatial behavior of the processes (see Hunka et al. (2025) for further details). Note, the observed values $y(\boldsymbol{s})$ are often transformed for model fitting (e.g., square-root or cube-root transformation is applied to the NFI- estimated volume or AGBD). The purpose of applying such a transformation is that it may help to linearize the relation between the observations and covariates (we assume such a linear relationship in eq. 1). Second, the transformation may help make the residuals (around a regression line) approximately normally distributed and account for heteroskedasticity. In the case of RoS, a cube-root transformation was found suitable. Upon model fitting, parameters α, β, η, $\tilde{\alpha}(\boldsymbol{s})$, $\tilde{\beta}(\boldsymbol{s})$ and $\tilde{\eta}(\boldsymbol{s})$ are outputted, thereby allowing the prediction of vegetation volume or AGBD at any given location with the EO-based covariates.

Model inference was conducted through Bayesian methods. In Bayesian methods, predictions are expressed as *posterior predictive distributions*, i.e., probability distributions of the unknown quantity based on observed data and model assumptions (for example, the distribution of model parameters is illustrated in Figure 2a). To predict vegetation AGBD or volume with the model, numerical methods are required. This means, samples may be drawn from the posterior distributions of model parameters/effects multiple times, and predictions of AGBD/volume may be made with these samples multiple times. The resulting posterior predictions of vegetation volume or AGBD can be used to produce interpretable summaries, such as expected mean values of AGBD or volume, their standard deviations (SDs) or uncertainty, and their 95% credible intervals (CIs). Such numerical approximations to predicted mean values, SDs, and 95% CIs of vegetation volume or AGBD are illustrated further in Figure 2b and c, and described in equations below.

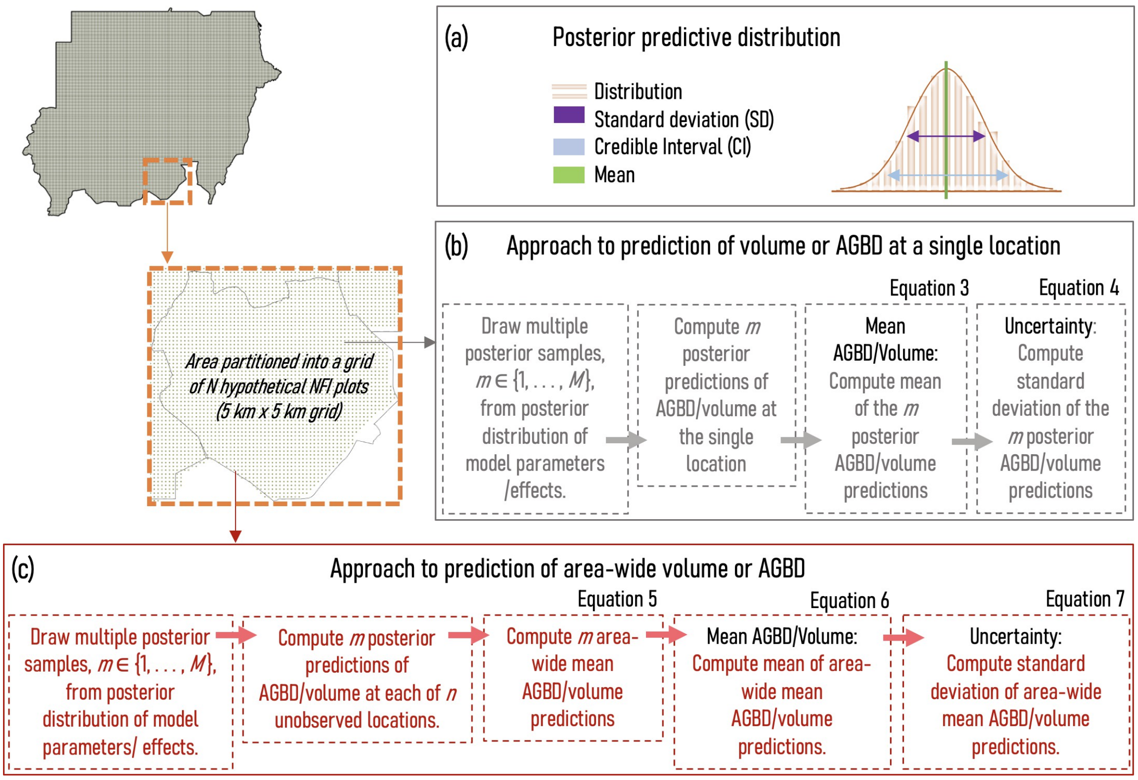


Figure 2: Approach to Bayesian inference and posterior prediction of vegetation volume or AGBD at either a single location or across an arbitrary area. Equation numbers are indicated on this illustration to relate the steps to the described methodology.

Let s_* represent a desired prediction location (such as an unvisited NFI plot), where the posterior distribution of vegetation volume or biomass must be approximated. Following the methods in Hunka et al. (2025), $m = 1, \ldots, M$ random samples are drawn from the posterior distribution of model parameters/effects. Samples from the pertinent parameters/effects are then plugged into the model (eq. 1) to yield posterior samples for vegetation volume or AGBD, $y(s_*)$, at the location s_*:

Properties of the posterior distribution, such as the expected mean value, $\overline{y}(s_*)$, and SD, $\sigma(s_*)$, of AGBD, can then be approximated with the corresponding sample quantities,

$$y_{(m)}(\boldsymbol{s}_*) = \Big(\alpha_{(m)}+\tilde{\alpha}_{(m)}(\boldsymbol{s}_*)\Big)+\Big(\beta_{(m)}+\tilde{\beta}_{(m)}(\boldsymbol{s}_*)\Big)x_1(\boldsymbol{s}_*)+\Big(\eta_{(m)}+\tilde{\eta}_{(m)}(\boldsymbol{s}_*)\Big)x_2(\boldsymbol{s}_*)+\epsilon_{(m)}(\boldsymbol{s}_*). \tag{2}$$

$$\overline{y}(\boldsymbol{s}_*) = \frac{1}{M}\sum_{m=1}^{M} y_{(m)}(\boldsymbol{s}_*), \tag{3}$$

$$\sigma(\boldsymbol{s}_*) = \sqrt{\frac{1}{M-1}\sum_{m=1}^{M}(y_{(m)}(\boldsymbol{s}_*) - \overline{y}(\boldsymbol{s}_*))^2} \ . \tag{4}$$

Over any arbitrary geographic area larger than the size of a single NFI plot, inference of area-wide mean volume or AGBD and its associated uncertainty involves analyses of posterior predictions at multiple locations within the area. Assume the desired area, A, can be partitioned into a grid of N hypothetical NFI plots at locations $s_{1,*}, \ldots, s_{N,*}$. The area-wide volume or AGBD, $y_{(m)}(A)$, is then

$$y_{(m)}(A) = \frac{1}{N}\sum_{i=1}^{N} y_{(m)}(\boldsymbol{s}_{i,*}). \tag{5}$$

As $m = 1, \ldots, M$ random samples are drawn from the posterior distribution of model parameters, the mean area-wide AGBD, $\overline{y}(A)$, and standard deviation, $\sigma(A)$, is:

$$\overline{y}(A) = \frac{1}{M}\sum_{m=1}^{M} \overline{y}_{(m)}(A), \tag{6}$$

$$\sigma(A) = \sqrt{\frac{1}{M-1}\sum_{m=1}^{M}(\overline{y}_{(m)}(A) - \overline{y}(A))^2} \ . \tag{7}$$

To gauge the accuracy of the posterior predictions of vegetation AGBD and volume (in comparison to the NFI estimates), an R-squared metric and root mean squared error (RMSE) serve as heuristics and are reported. These are estimated as,

$$\widetilde{\mathrm{R}}^2 = 1 - \frac{\sum_{i=1}^{t_*} \left(\mathrm{E}[y(\boldsymbol{s}_{*,i})] - y(\boldsymbol{s}_{*,i})\right)^2}{\sum_{i=1}^{t_*} \left(y(\boldsymbol{s}_{*,i}) - \bar{y}_*\right)^2} \tag{8}$$

$$\widetilde{\mathrm{RMSE}} = \sqrt{\frac{\sum_{i=1}^{t_*} \left(\mathrm{E}[y(\boldsymbol{s}_{*,i})] - y(\boldsymbol{s}_{*,i})\right)^2}{t_*}} \tag{9}$$

where $s_{*,i}$; $i \in \{1, \ldots, t_*\}$ are the locations with NFI-estimated $y(s_{*,i})$, $\bar{y}_*$ is the mean of those observed values, and $\mathrm{E}[y(s_{*,i})]$ are posterior mean predictions at the training or testing locations.

Further, the coverage rate of the 95% credible intervals (CIs), i.e. the proportion of NFI-estimates lying within the 95% CIs of our model volume or AGBD predictions, is reported. A coverage rate of close to 95% is the ideal scenario. Coverage rates below 95% will indicate that model uncertainties may be overly optimistic, while rates above 95% suggests that uncertainties could be overly conservative (see May et al., 2023; Hunka et al., 2025).

Assessing model results and validation

Model validation is conducted primarily through leave-one-out cross validation during the process of model fitting in R-INLA. A cross-validated Probability Integral Trans- form (PIT) is generated, which assesses, for each observation, the probability that the posterior mean prediction will be less than or equal to the observed value (David and Johnson, 1948).

$$\mathrm{PIT}_i = \mathrm{Prob}(y_i^{pred} \leq y_i^{obs} | y_{-i}), \tag{10}$$

where y_i^{pred} is the prediction where y_i^{obs} is the observed value, and y_{-i} denotes the observations with the ith observation omitted. When the model accurately represents the observations, the PIT scores are expected to be uniformly distributed between 0 and 1. Further, we report the coverage rate of the 95% credible intervals (CIs) of left-out samples. In the ideal case, approximately 95% of cases, the left-out sample will have a PIT score between 0.025 and 0.975.

Open-source Code Availability

The model for Sudan was run in R using package R-INLA (R Core Team, 2022; Lindgren and Rue, 2015), which executes efficient geostatistical model fitting and the prediction of vegetation volume or AGBD (Gómez Rubio, 2020, Chapter 7). The source code is publicly released and is available on the NASA Carbon Monitoring Systems Biomass Harmonization GitHub repository. Upon review, the code may be published with a permanent DOI record for use for Sudan's vegetation assessments in the future.

Results

Model performance

The geostatistical model reveals a strong relation between the covariates (i.e., NASA GEDI biomass and the Forest Non-Forest Probability Map 2023) and the observations

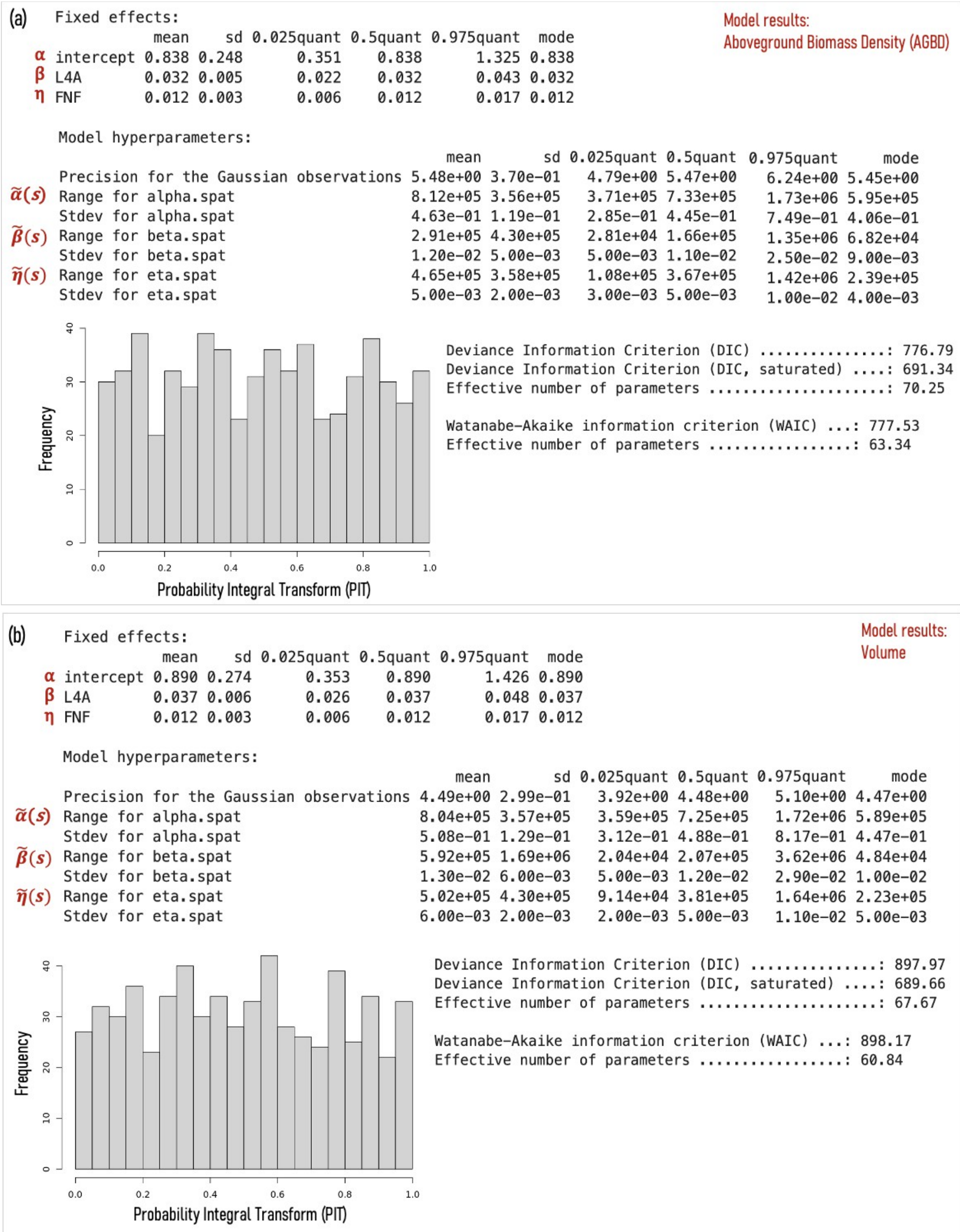


Figure 3: Results of the geostatistical model for prediction of aboveground biomass (AGBD, a) and volume (b), including model parameters and effects. Histograms show the Probability Integral Transform (PIT).

(i.e., NFI-estimated AGBD or volume) across Sudan. The model explains approximately 72% and 69% of the variability in the NFI-estimates of volume and AGBD respectively (Figure 4). Corresponding model RMSEs are low, and there is no strong evidence of systematic deviations (empirical bias) in model predictions, with difference in means less than 1 Mg/ha or 1 m^3/ha for AGBD and volume respectively. An appropriate coverage rate of the 95% CIs is noted. Model parameters, including the fixed effects (α, β and η) and the spatially-varying random effects ($\tilde{\alpha}(\boldsymbol{s})$, $\tilde{\beta}(\boldsymbol{s})$ and $\tilde{\eta}(\boldsymbol{s})$) are shown in Figure 3. The leave-one-out cross-validation resulted in a fairly uniform distribution of PITs (see eq. 10), implying that the posterior samples of predicted AGBD and volume do not have a larger probability of being over- or under-predictions when compared to their observed values. For the posterior pre- dictions of AGBD and Volume, approximately 94.3% and 94.8% of PIT scores fall between values 0.025 and 0.975, indicating strong model performance.

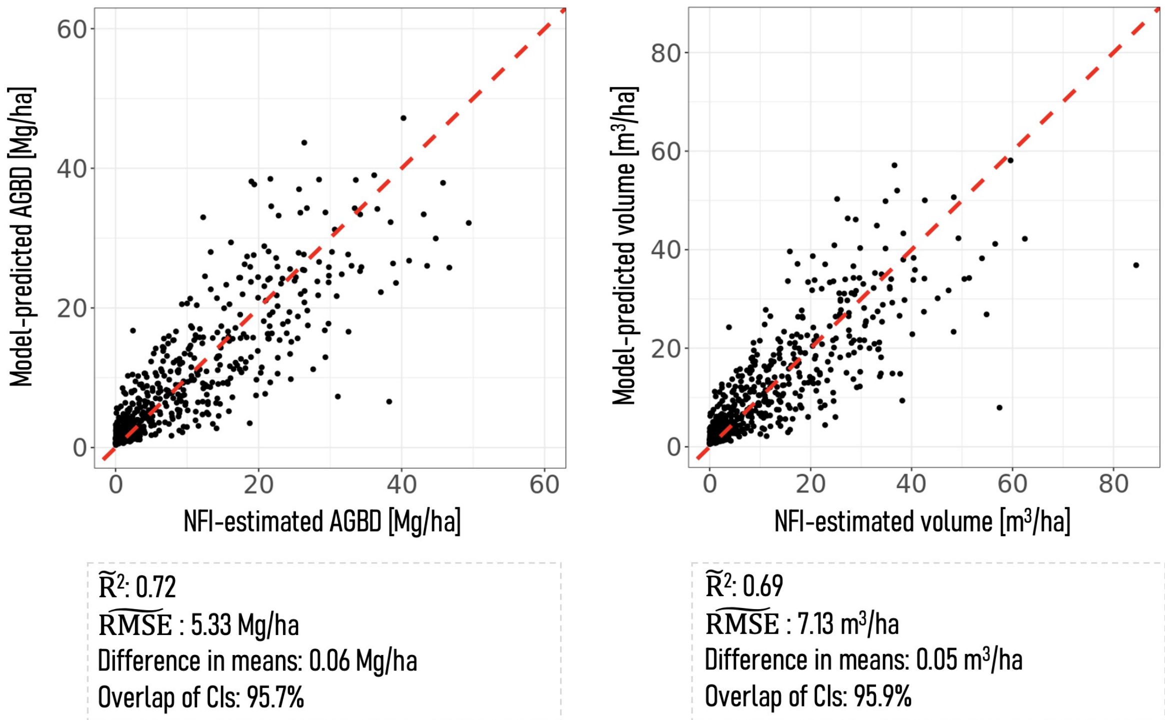


Figure 4: Posterior mean predictions of vegetation aboveground biomass density (AGBD, left) and volume (right) from the geostatistical model (eq 1), plotted against their NFI-estimated values.

Predictions of aboveground biomass and volume

The primary purpose of using auxiliary EO datasets in support of the Sudanese NFI is allowing the prediction of AGBD or volume in under-sampled areas due to accessibility and/or logistic constraints. For area-wide predictions, a hypothetical grid is constructed for areas of interest (for example, in every state in Sudan) and predictions of AGBD or volume are made at each grid node (using eqs. 3 and 4). The density of this hypothetical grid may be as dense as wall-to-wall NFI plots, but a 5 km × 5 km was found sufficiently dense to provide high-precision area-wide summary statistics.

An example of AGBD predictions for the state of Southern Kordufan is displayed in Figure 5, where the NFI plots are sparse. As the geostatistical model allows drawing information from

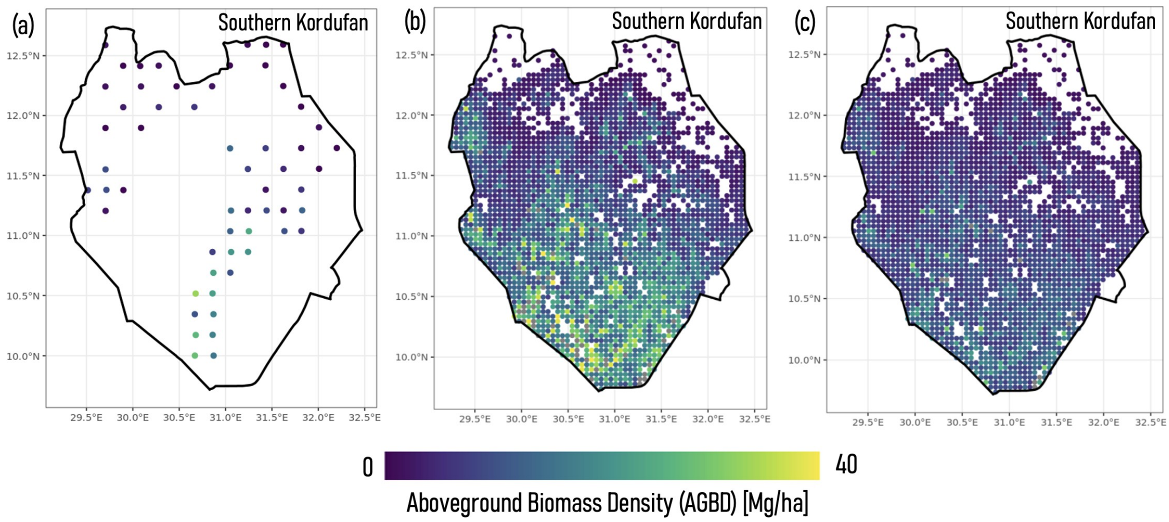
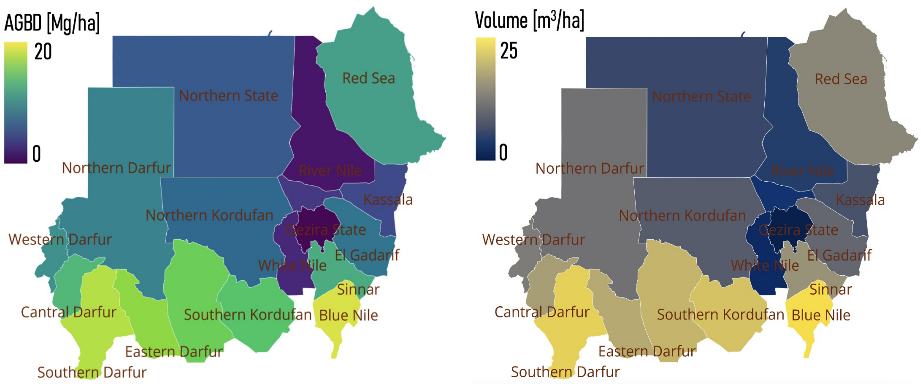


Figure 5: Example of results of the geostatistical model for the state of Southern Kordufan - (a) NFI-estimated AGBD, (b) model predicted mean AGBD and (c) uncertainty of AGBD in model predictions. For the model predictions, a hypothetical 5 km × 5 km grid is created across the extent of the state. Where the Forest Non-Forest (FNF) Probability Map 2023 indicates >10% probability of forest, a prediction using the geostatistical model is made and displayed in this figure. All values are in the units of



Mg/ha.

Figure 6: State-level predictions of vegetation aboveground biomass density (AGBD, left) and volume (right) from the geostatistical model. Predictions are only made over lands where the Forest Non-Forest (FNF) Probability Map 2023 indicates >10% probability of forest.

the auxiliary EO layers at any location, it allows predictions at all nodes of the 5 km × 5 km grid. This provides a spatially-dense and spatially-complete set of predictions for the state (note, no predictions are made in areas of ≤10% forest probability). Finally, these predictions are summarized to area-wide summaries (using eqs. 6 and 7). State-level predictions of vegetation AGBD and volume for all states in Sudan are provided in Figure 6 and Table 1.

State	**AGBD** [Mg/ha]	**AGBD SD** [Mg/ha]	**Volume** [m3/ha]	**Volume SD** [m3/ha]
Blue Nile	21.08	5.77	30.90	8.38
El Gadarif	2.89	0.67	4.29	0.92
Gezira State	1.03	0.46	1.34	0.64
Kassala	1.33	0.69	2.22	1.14
Khartoum State	1.25	0.59	1.95	0.97
Northern State	1.70	1.44	2.15	1.74
Northern Darfur	4.17	0.70	4.95	0.76
Northern Kordufan	2.66	0.54	3.44	0.62
Red Sea	5.93	3.23	8.92	4.56
River Nile	1.08	0.77	1.96	1.42
Sinnar	9.63	1.75	11.31	2.11
Southern Darfur	18.27	2.26	24.19	3.02
Southern Kordufan	17.13	5.19	21.90	5.35
Central Darfur	11.61	1.03	15.52	1.38
White Nile	1.09	0.35	1.46	0.49
Western Darfur	4.93	0.91	5.71	0.90
Eastern Darfur	17.88	1.16	20.47	1.44
Western Kordufan	17.78	1.35	21.34	1.51

Table 1: State-level predictions of vegetation aboveground biomass density (AGBD) and volume estimates, and their uncertainty (standard deviation, SD) across Sudan. Predictions are only made over lands where the Forest Non-Forest (FNF) Probability Map 2023 indicates >10% probability of forest.

References

Babcock, C., Finley, A.O., Andersen, H.E., Pattison, R., Cook, B.D., Morton, D.C., Alonzo, M., Nelson, R., Gregoire, T., Ene, L., Gobakken, T., Næsset, E., 2018. Geostatistical estimation of forest biomass in interior Alaska combining Landsat- derived tree cover, sampled airborne lidar and field observations. Remote Sensing of Environment 212, 212–230. URL: http://dx.doi.org/10.1016/j.rse.2018.

04.044, doi:10.1016/j.rse.2018.04.044.

Breidenbach, J., Ivanovs, J., Kangas, A., Nord-Larsen, T., Nilsson, M., Astrup, R., 2021. Improving living biomass C-stock loss estimates by combining optical satellite, airborne laser scanning, and NFI data. Canadian Journal of Forest Research 51, 1472–1485. URL: http://dx.doi.org/10.1139/cjfr-2020-0518, doi:10.1139/cjfr-2020-0518.

David, F.N., Johnson, N.L., 1948. The probability integral transformation when parameters are estimated from the sample. Biometrika 35, 182. URL: http://dx. doi.org/10.2307/2332638, doi:10.2307/2332638.

Dubayah, R., Blair, J.B., Goetz, S., Fatoyinbo, L., Hansen, M., Healey, S., Hofton, M., Hurtt, G., Kellner, J., Luthcke, S., Armston, J., Tang, H., Dun- canson, L., Hancock, S., Jantz, P., Marselis, S., Patterson, P.L., Qi, W., Silva, C., 2020. The Global Ecosystem Dynamics Investigation: High-resolution laser ranging of the Earth's forests and topography. Science of Remote Sensing 1, 100002. URL: https://www.sciencedirect.com/science/article/pii/S2666017220300018, doi:https://doi.org/10.1016/j.srs.2020.100002.

Dubayah, R., Hofton, M., Blair, J., Armston, J., Tang, H., Luthcke, S., 2021. GEDI L2A Elevation and Height Metrics Data Global Footprint Level V002. URL: https://lpdaac.usgs.gov/products/gedi02_av002/, doi:10.5067/GEDI/ GEDI02_A.002.

Duncanson, L., Kellner, J.R., Armston, J., Dubayah, R., Minor, D.M., Hancock, S., Healey, S.P., Patterson, P.L., Saarela, S., Marselis, S., Silva, C.E., Bruen- ing, J., Goetz, S.J., Tang, H., Hofton, M., Blair, B., Luthcke, S., Fatoyinbo, L., Abernethy, K., Alonso, A., Andersen, H.E., Aplin, P., Baker, T.R., Barbier, N., Bastin, J.F., Biber, P., Boeckx, P., Bogaert, J., Boschetti, L., Boucher, P.B., Boyd, D.S., Burslem, D.F., Calvo-Rodriguez, S., Chave, J., Chazdon, R.L., Clark, D.B., Clark, D.A., Cohen, W.B., Coomes, D.A., Corona, P., Cushman, K., Cutler, M.E., Dalling, J.W., Dalponte, M., Dash, J., de Miguel, S., Deng, S., Ellis, P.W., Erasmus, B., Fekety, P.A., Fernandez-Landa, A., Ferraz, A., Fischer, R., Fisher, A.G., García-Abril, A., Gobakken, T., Hacker, J.M., Heurich, M., Hill, R.A., Hopkinson, C., Huang, H., Hubbell, S.P., Hudak, A.T., Huth, A., Imbach, B., Jeffery, K.J., Katoh, M., Kearsley, E., Kenfack, D., Kljun, N., Knapp, N., Král, K., Krůček, M., Labrière, N., Lewis, S.L., Longo, M., Lucas, R.M., Main, R., Manzanera, J.A., Martínez, R.V., Mathieu, R., Memiaghe, H., Meyer, V., Men- doza, A.M., Monerris, A., Montesano, P., Morsdorf, F., Næsset, E., Naidoo, L., Nilus, R., O'Brien, M., Orwig, D.A., Papathanassiou, K., Parker, G., Philipson, C., Phillips, O.L., Pisek, J., Poulsen, J.R., Pretzsch, H., Rüdiger, C., Saatchi, S., Sanchez-Azofeifa, A., Sanchez-Lopez, N., Scholes, R., Silva, C.A., Simard, M., Skidmore, A., Stereńczak, K., Tanase, M., Torresan, C., Valbuena, R., Ver- beeck, H., Vrska, T., Wessels, K., White, J.C., White, L.J., Zahabu, E., Zgraggen, C., 2022. Aboveground biomass density models for NASA's Global Ecosystem Dynamics Investigation (GEDI) lidar mission. Remote Sensing of Environment 270, 112845. URL: https://www.sciencedirect.com/science/article/pii/S0034425721005654, doi:https://doi.org/10.1016/j.rse.2021.112845.

Emick, E., Babcock, C., White, G.W., Hudak, A.T., Domke, G.M., Finley, A.O., 2023. An approach to estimating forest biomass while quantifying estimate uncer- tainty and correcting bias in machine learning maps. Remote Sensing of Environ- ment 295, 113678. doi:10.1016/j.rse.2023.113678.

Gelfand, A.E., Schliep, E.M., 2016. Spatial statistics and Gaussian processes: A beautiful marriage. Spatial Statistics 18, 86–104. URL: https://doi.org/10. 1016/j.spasta.2016.03.006.

Gómez Rubio, V., 2020. Bayesian Inference with INLA. doi:10.1201/9781315175584.

Hunka, N., May, P., Babcock, C., de la Rosa, J.A.A., de los Ángeles Soriano- Luna, M., Saucedo, R.M., Armston, J., Santoro, M., Suarez, D.R., Herold, M., Málaga, N., Healey, S.P., Kennedy, R.E., Hudak, A.T., Duncanson, L., 2025. A geostatistical approach to enhancing national forest biomass assessments with earth observation to aid climate policy needs. Remote Sensing of Environment 318, 114557. URL: https://www.sciencedirect.com/science/article/pii/S0034425724005832, doi:https://doi.org/10.1016/j.rse.2024.114557.

Lindgren, F., Rue, H., 2015. Bayesian Spatial Modelling with R-INLA. Journal of Statistical Software 63, 1–25. URL: https://www.jstatsoft.org/index.php/ jss/article/view/v063i19, doi:10.18637/jss.v063.i19.

May, P., McConville, K.S., Moisen, G.G., Bruening, J., Dubayah, R., 2023. A spatially varying model for small area estimates of biomass density across the contiguous United States. Remote Sensing of Environment 286, 113420. URL: https://www. sciencedirect.com/science/article/pii/S0034425722005260,

doi:https:// doi.org/10.1016/j.rse.2022.113420.

R Core Team, 2022. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. Vienna, Austria. URL: https://www. R-project.org/.

Annex 8: Response Design

Response Design and Explanatory variables for Activity Data
IPCC land cover classes[1]
Republic of Sudan, FLR, 2024

1. **Data Collection on LULC Classes for 2023**

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.

Republic of Sudan's National Forest Corporation (FNC) defines forest as;
"an area of land spanning at least a minimum area of 0.4 ha with trees that have attained or have the potential to attain at least 2 m in height and a minimum tree canopy cover of 10%. It includes windbreaks and/or shelterbelts with a minimum of 20 m in width".

Explanatory variables

- It does not include land that is predominantly under agricultural or urban land use.
- Forest is determined both by the presence of trees and the absence of other predominant land uses.
- The trees should be able to reach a minimum height of 2 meters in situ.
- Includes forest roads, 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 plantation for restoration purposes. Young natural stands and all plantations established for forestry purposes which have yet to reach a crown density of 10 percent or tree height of 2 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, oil palm plantations, olive orchards, and agroforestry systems when crops are grown under tree cover.
-

1.1.1. Tree Cover Forest

Count the no. of yellow dots in plot falling over trees and record in the survey, each subplot represents 2 percent of plot.

Explanatory Variable

- This option will only be available when LULC cover is forestland
- Tree cover forest refers to trees only in forest area
- Which means trees standing agricultural land or urban setting should not be included
- Respect the forest definition height when counting trees inside the forest area (2m)
- Do not confuse this with shrubland

1.2. Cropland

This category includes arable and tillage land, and agro-forestry 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 where the vegetation structure falls below the thresholds in the national definition used for the Forest land category (< 10% crown cover and < 20 m in width for windbreaks and/or shelterbelts).
- 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 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

1.3. Grassland

This category includes **rangelands and pastureland** that is not considered as cropland. It also includes systems with vegetation that fall below the **threshold used in the forest land category and are not expected to exceed (trees < 2 meter in height)**, without human intervention, the threshold used in the forest land category. 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 (e.g. with fertilization, irrigation, species changes) continuous pasture and hay land.

- Grasslands generally have a 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** 10 percent.
- **Grasslands includes 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 tress where height is less than 2 meter).
- **Includes Savanna or savannah – mixed woodland-grassland ecosystem.**

1.4 Wetlands

This category includes land that is covered or **saturated by water for** all or part of the year (e.g., **peatland)** and that does not fall into the forest land, cropland, grassland or settlements categories. It includes reservoirs as a 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.**

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.

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.

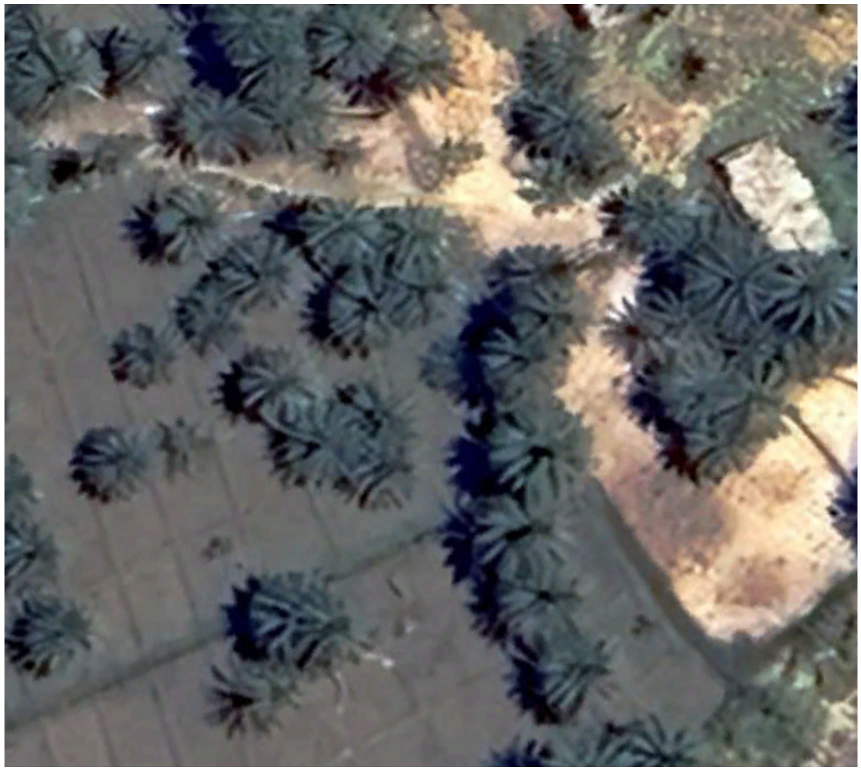
Explanatory variables

- 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.
- Active Mine dump generally but also include the dumps if not active.

1.7. Plantation

Includes commercial plantation like pine, eucalyptus, Acacia and others.
For Example, Citrus Trees near to riverbank in Northern, river Nile, Kassala and Khartoum states.

Another example is Date Palm tree near to riverbank in northern and river Nile state.


Date palm tree plantation

2. **Recording Changes over the FRL Period (2023-2011)**

2.1. Forest Loss (Deforestation)

Forest land changed to non-forest land during 2023-2011

This includes both changes in land use and reduction of canopy cover below forest threshold:

- When percentage tree cover is above 10% but land use change is observed as a major activity e.g. Forest land converted to cropland
- When percentage tree+ cover is reduced from >10 % to < 10% but no LULC change is observed
- Percentage tree cover reduced to < 10 percent and LULC change is also observed
- Example: Heterogeneous plot: e.g. if a plot is showing 50% change but still has intact forest at 50%. Then considering context, if change is beyond the limit of plot that means its deforestation. If only inside the plot, then must flag that plot as no confidence for further review, should be flagged as “degradation”

Tips: Use the Majority rule while collecting data, always consider context before making decision to better understand the landscape, for example a plot might meet the forest definition criteria but if you zoom out and check the context it could be locate under the urban settings or agricultural area, in that case this will not be consider as forest.

Examples

- Forest land converted to plantation.
- Forest land converted to settlement.
- Forest land converted to cropland.
- 2018 was a forest and in 2022 converted to cropland and percentage tree cover is still meeting forest definition criteria (12 %), this will be classified as deforestation because Land use change is being observed
-

2.2. Forest Enchantement (NF-F/ F- F)

Forest enhancement is equivalent to the IPCC category of Land Converted to Forestland, but the conversion is being observed during the reference period (2011-2023)

Forest enhancement in the context of RoS is defined as conversion of croplands and bare lands within degraded forest land use (mostly subject to cultivation) to forestland through human-induced afforestation and reforestation. This enhancement of carbon stoke is being observed during reference period (2023- 2011).

- Forest plantation/ regeneration on cropland being observed to exist first in or after year 2011 and continue to exist tell 2023.
  - Plantation over bare land near/within degraded forest land being observed to exist first in or after year 2011 and continue to exist till 2023).
- It’s opposite of degradation.
- Should include all **afforestation and reforestation activities**.
- Should **not include natural succession.**

2.3. Forest Gain

It should include **non-forest land converted to forest land**. But make sure it’s meeting forest definition criteria (tree cover > 10% and 2m height).

- Its increase in tree canopy cover observed over reference period (e.g. from <10 % to >10%).
- It is opposite to forest loss, include all-**natural forest regeneration.**
- Natural succession of bare land degraded land.
- Not already addressed under enhancement class.

2.4. Forest Degradation (F-F)

Forest degradation is defined as **reduction in canopy cover** in this assignment context.

- It will be a Forestland remains Forestland but only percentage tree cover reduced over time (2023- 2011).
- Reduction in canopy cover but total tree cover should remain **equal or greater than 10%**
  Examples percentage of canopy cover is reduced to less than 30% in 2017 from 90% in 2016
- When canopy cover reduced to less than 10% even without LULC changes, that’s **“Deforestation” NOT “Degradation”.**
- Reduction of canopy cover but still have percentage of forest cover as of forest definition.

2.5. NF – NF LULC Changes

- Any LULC changes not addressed above will be included here.
-

2.6. No Changes

[1] https://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/Chp2/Chp2_Land_Areas.pdf

Annex 9: Members of Steering Committee, FRL Taskforce, Remote Sensing Team and Management and Technical Support Team

Members of the National REDD+ Steering Committee

No.	Name	Gender	Institution
1	Anwar Abdelhameid	M	FNC/ Director General
2	Prof. Essam Warrag	M	FAO Representative
3	Mohamed Ahmed Elfadil	M	Ministry of Finance and economic development
4	Dr. Mona Mohamed Ali	F	Higher Council of Environment and Natural Resources
5	Adil Mohamed Ali	M	Sudanese Environmental Conservation Society
6	Representative		University of Khartoum
7	Dr. Nuha Mutwali	F	Forestry Research Centre
8	Abdelmonem Adris	M	Range and Pasture
9	Yahyia Adam Abdalla	M	FNC
10	Sawsan Abdalla	F	FNC
11	Dr. Sayeda A. Khalil	F	REDD+ Coordinator

Members of the FRL Taskforce

No.	Name	Gender	Institution/ State
1	Adam Mohamed Adam Abdullah	M	FNC/HQ
2	Amir Mohamed Ahmed Saleh	M	FNC/HQ
3	Mutasim Fadl Elseed Babiker	M	FNC/HQ
4	Manal Ali Yassn Ibrahim	F	FNC/HQ
5	Hanady Ibrahim Abdul Jabbar	F	FNC/HQ
6	Ali Haroun Ali	M	University of Khartoum
7	Azza Ahmed Al-Tayeb	F	HCENR
8	Mohamed Awad Mohamed	M	Red See State/FNC
9	Hatim Al-Ubaid Ibrahim	M	RSSA
10	Safaa Ahmed Brima Hamed	F	FNC/HQ
11	Mona Mohamed Rakhi	F	North Kordofan state/FNC
12	Fatima Abdelwahid Abdalla	F	RSSA
13	Zahir Dafaa Alla	M	Gedarif State/FNC

14	Osman Adam Babiker	M	North State/FNC
15	Khalda Abbas Hassan Elgzouli	M	FNC/HQ
16	Osman Abdalla	M	FNC/HQ
17	Khidir Salah	M	REDD+ PMU

Members of Republic of Sudan Remote Sensing Team Participated in Activity Data Collection

No.	Name	Gender	E-Mail	Institution
1	Mohamed Osama	M	osama.mohamed@fao.org	FAO
2	Fatima Abdelwahid Abdalla	F	Abdallatana@gmail.com	RSSA
4	Wala Hassan Abdelrahman Musnad	F	walaa_musnad@yahoo.com	RSSA
5	Khalda Abbas Hassan Elgzouli	F	hassan_khalda@yahoo.com	FNC
6	Amani AmadEldin ElshiekhIdrees Mahmoud	F	emooemadaldin55@gmail.com	RSSA
7	Egbal Hashim Mohamed Elnageeb	F	egbal44@hotmail.com	RSSA
8	Safaa Ahmed Beraima Hamid	F	safaaberaima2007@gmail.com	FNC
9	Solafa Babiker Mohamed Babiker	F	babiker.solafa@gmail.com	RSSA
10	Hanady Ibrahim Abdelgabbar Ali	F	hanady552017@gmail.com	FNC
11	Hanadi Kamal-eldin Ahmed Yagoub	F	hanadikamaleldin@gmail.com	FNC
12	safa Khalid Yousif Alkhadir	F	safakhalid2016@gmail.com	RSSA
13	Omnia Omer Dffelseed Hamid	F	omniaomer4@gmail.com	RSSA
14	Mutasim Fadl Elseed Babiker	M	mutasim552017@gmail.com	FNC
15	Hatim Nuh	M	hatimoo22@yahoo.com	RSSA
16	Hebatalla Eltayeb Ali Awadalla	F	Hebaeltayeb27@gmail.com	RSSA
17	Mohaned Eltijani Mohamed Elmardi	M	hody.mohamed@gmail.com	RSSA
18	Manal yaseen	F	manalfncorp76@gmail.com	FNC
19	Zahir Dafalla Abo Agla	M	zahrdfallh4@gmail.com	FNC

Management and technical support team

No	Name	Gender	Role	Institution
	Sayeda Ahmed Khalil	F	Coordinator, REDD+ PMU	FNC
	Igbokwe Kennedy	M	Project Management support	FAO
	Essam Warrag	M	Project Management support	FAO
	Anwar Sidahmed	F	Project Management support	FAO
	Marieke Sandker	F	Technical Support	FAO
	Naila Yasmin	F	Technical Support	FAO
	Osama Mohamed	M	Remote Sensing Expert	National consultant
	Nagmeldin Mahmoud	M	FRL Expert	National consultant