GREEN HOUSE GAS INVETORY OF FORESTRY SECTOR – SINDH PROVINCE

Ministry of Climate Change

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Table of Contents

List of Tables 3

List of figures 3

ACRONYMS 4

EXECUTIVE SUMMARY 7

1. INTRODUCTION 8

1.1. Brief introduction of Sindh Province 8

1.2. Objectives of the carbon stock assessment 8

1.3. Process adopted for the GHG-Inventory 9

1.1.1. Adjustment and adoption of the national standards 9

1.1.2. Field and Satellite Based Inventories 11

2. ESTIMATION OF FOREST CARBON STOCK AND EMISSIONS 11

2.1. Area Covered 11

2.2. Carbon Pools and Gases 11

2.3. Activities Covered 11

2.4. Consistency with National GHG Inventory 12

3. DATA, METHODOLOGY AND PROCEDURE 12

3.1. Mapping of Activity Data for Deforestation 12

3.2. Mapping of Activity Data for Forest Degradation 16

3.3. Mapping of Activity Data for Enhancement of Carbon Stock 16

3.4. Emission Factors for Deforestation 16

3.4.1. Sampling Design 16

3.4.2. National Forest Inventory Protocol 20

3.4.3. Data Storage and Processing 23

3.4.4. Diameter-Height model development 24

3.4.5. Allometric models for Above-Ground Tree Biomass estimation 27

3.5. Emission Factors for Forest Degradation 27

3.6. Reference Period 28

3.7. Emissions Calculation 28

3.8. Emission Calculation from Deforestation 28

3.9. Emission Calculation from Forest Degradation 29

3.10. Removal/Sequestration from Enhancement 29

4. RESULTS 30
4.1. Forest Type Wise Carbon Stock 30
4.2. Emission Factors for Deforestation 30
4.3. Estimates of Deforestation 31
4.4. Estimates of Forest Degradation 31
4.5. Estimates of Enhancement 32
4.6. Emissions from Deforestation 32
4.7. Emission Factors for Forest Degradation 34
4.8. Emissions and Removals from Forest Degradation and Improvement in Forest Cover Density 34
4.9. Removals from Enhancement 35
4.10. Overall situation of emissions and removals 35
5. RECOMMENDATIONS FOR IMPROVEMENT 37
5.1. Improvement of Activity Data 37
5.2. Improvement of Emission Factors 37
6. REFERENCES 38
7. ANNEXES 41
Annex 1. Forest Inventory Plots Location Map (Sindh) 41
Annex-2: Coordinates of accessible forest inventory sample plots (clusters) in Sindh 42
Annex-3: Forest types map of Sindh 43
Annex-4: LULC Maps 2016-Sindh 44
Annex-5: LULC Maps 2020-Sindh 45
Annex-6: Land Use Land Cover Change Map of Sindh 46
Annex-7. Wood Densities by Species (adopted from National FREL/ FRL Report 2020) 47
Annex-8: Revised Forest measurement manual (provided as separate file) 47
Annex-9: Data Storage and Processing report (provided as separate file) 47
Annex-10: Forest type and pool wise breakup of carbon densities (with and without SOC) 48
Annex-11: Details of emissions from forest degradations 48
Annex-12: Details of removals from improvement in forest cover density 49
Annex-13: Uncertainties of Emission Factors of deforestation 49
Annex-14: Uncertainties of Emission Factors of Forest Degradation 50
Annex-15: Province wise uncertainties of Activity Data (Forest Loss) 51
Annex-16: Mean Ages of Different Forest Types 51

List of Tables

Table 1: National Forest type stratification with adjustments 10
Table 2: Details of the Landsat-8 images downloaded for one Year 12
Table 3: Province wise Landsat-8 images processed for Classification 13
Table 4: Province wise number of interpreted plots and plots density 14
Table 5: Province wise number of sample plots 17
Table 6: Diameter-Height Models developed during initial stage 25
Table 7: Finally selected Diameter-Height Models with descriptive statistics 26
Table 8: Allometric models applied for Above Ground Biomass estimation 27
Table 9: Formulas used to derive the emission factors for deforestation 28
Table 10: Default values of carbon densities in non-forest land use classes adopted for EFs/RFs of deforestation/ Enhancement 29
Table 11: Formulas used to derive the emission factor for forest degradation 29
Table 12: Formulas used to derive the removal factors (RF) for enhancement 30
Table 13: Carbon stocks in different forest types 30
Table 14: Emission Factors for Deforestation (excluding soil organic carbon) 31
Table 15: Estimates of deforestation in different forest types 31
Table 16: Estimates of Forest Degradation 31
Table 17: Estimates of Enhancements 32
Table 18: Emissions from Deforestation 33
Table 19: Emission factors for forest degradation 34
Table 20: Emissions from Forest Degradation 34
Table 21: Removals from enhancement 36
Table 22: Overall carbon emissions and removals 36

List of figures

Figure 1: Stratified two-phase sampling process with integration of the SLMS process 18
Figure 2: Clustered primary and secondary sample units (plots). Source: NFMS, 2020 19
Figure 3: Clustered primary and secondary sample units (plots) for mangrove forests. Source: NFMS, 2020 19
Figure 4: Forest Inventory Workflow (Source: adopted from NFMS-MRV Report, 2020) 20
Figure 5:Data storage and processing workflow 24
Figure 6: Distribution of Emissions from Deforestation 32

ACRONYMS

AD	Activity data
AGB	Above Ground Biomass
AJK	Azad Jammu & Kashmir (autonomous territory)
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
BGB	Belowground Biomass
BGC	Belowground Carbon
CCF	Chief Conservator Forest
CCW	Chief Conservator Wildlife
CD	Community Development
CF	Conservator Forest
CO2	Carbon Dioxide
COP	Conference of Parties
CP	Conference of Parties (Decision references)
CSO	Civil Society Organization
CSV	Comma-separated Values
DBH	Diameter at Breast Height
DEM	Digital Elevation Model
D-H	Diameter-Height
DW	Dead Wood
EF	Emission Factor
Emiss.	Emission
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization of the United Nations
FD	Forest Department (provincial)
FATA	Federally Administered Tribal Areas
FOSS	Free and Open-Source Software
FPIC	Free, prior and informed consent
FREL	Forest Reference Emissions Levels
FRL	Forest Reference Levels
FSMP	Forestry Sector Master Plan
GB	Gilgit-Baltistan (autonomous territory
GCISC	Global Change Impact Studies Centre
GCP	Ground Control Point
GDEM	Global Digital Elevation Model
GHG-I	Greenhouse Gas Inventory
GIS	Geographic Information System
GOP	Government of Pakistan
GPS	Global Positioning System
GPS	Global Positioning System
GUI	Graphical User Interface ha Hectare (1 ha = 10,000 m2)

HR	High Resolution
ICIMOD	International Centre for Integrated Mountain Development
ICT	Islamabad Capital Territory (federal capital territory)
INGO	International Non-Governmental Organization
IPCC	Intergovernmental Panel on Climate Change
IT	Information Technology
IUCN	International Union for Conservation of Nature
km / km2	Kilometer / Square kilometer
KP	Khyber Pakhtunkhwa (province)
LCCS	FAO’s Land Cover Classification System
LiDAR	Light Detection and Ranging
LULC	Land Use Land Cover
LULUCF	Land Use, Land Use Change and Forestry
MBIGS	Multiple benefits, impacts, governance, safeguards
MMRV	Monitoring & Measurement, Reporting and Verification
MMU	Minimum Mapping Unit
MOCC	Ministry of Climate Change
MOE	Ministry of Environment
MRV	Measurement, Reporting and Verification
MSS	Multispectral Scanner
NASA	National Aeronautics and Space Administration
NCCA	National Climate Change Authority
NFI	National Forest Inventory
NFMS	National Forest Monitoring System
NGO	Non-governmental Organization
NRP	National REDD+ Program
NSC	National REDD+ Steering Committee
NSDI	National spatial data infrastructure
NTFP	Non-Timber Forest Product
NUST	National University of Sciences and Technology (NUST)
O&M	Operationalization and Maintenance
OBIA	Object Based Image Analysis
OGC	Open Geospatial Consortium
OIGF	Office of Inspector General of Forests
OLI	Operational Land Imager
PAMs	REDD+ Policies and Measures
PB	Punjab (province)
PBI	MS Power BI (A Microsoft Data Analysis Software)
PES	Payment of Ecosystem Services
PFI	Pakistan Forest Institute
PSU	Primary Sampling Unit

QA	Quality assurance
QC	Quality control
QGIS	Quantum GIS (Open-Source GIS Software)
R&D	Research & Development
REDD	Reducing Emissions from Deforestation and Forest Degradation
REDD+	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
Remov. / Rem.	Removal
RF	Removal Factor
ROI	Regions of Interest
R-PP	Readiness Preparation Proposal
RS	Remote Sensing
SAGA	System for Automated Geoscientific Analysis
SAR	Synthetic Aperture Radar
SCP	Semi-Automatic Classification
SD	Sindh (province)
SECP	Securities & Exchange Commission of Pakistan
SIS	Safeguard Information System
SLMS	Satellite Land Monitoring System
SOC	Soil Organic Carbon
SOP	Survey of Pakistan
SPOT	Satellite Pour l'Observation de la Terre (French satellite image provider)
SSL	Secure Sockets Layer
SSU	Secondary Sampling Unit
TWG	Technical REDD+ Working Group
UNDP	United Nations Development Program
UNEP	United Nations Environment Program
UNFCCC	The United Nations Framework Convention on Climate Change
US	The United States of America
USGS	US Geographical Survey
UTM	Universal Transverse Mercator (coordinate system)
VHR	Very High Resolution
WCS	The Open Geospatial Consortium Web Coverage Service Interface Standard
WWF-Pakistan	World Wide Fund for Nature

EXECUTIVE SUMMARY

The sub-national GHG-Inventory aims to contribute to the implementation of the NFMS and to determine the performance against the national FREL and FRL. Specific objectives of the assignment are; to assess the forest carbon stock for the reference period of 2016-2020; assess the carbon emissions from deforestation and forest degradation and removals from enhancement of carbon stocks for the reference period of 2016-2020; provide sub-national level figures for reporting on the national contribution to the mitigation of climate change, and; access the results-based REDD+ Finance for reducing emissions.

The current report covers the total area of the Sindh Province, that is 140,900 km^2.

Methodologies developed during under NFMS and FREL/ FRL 2020 were adopted with slight adjustments. National definition for Forest (2017) and national definition for forest degradation (2021) were adopted for generation of activity data, forest inventory and development of emission factors.

The SLMS part included acquisition of Landsat-8 imageries for 2016 and 2020, pre-processing of imageries, LULC change analysis using the NFMS and FREL/ FRL 2020 methodologies and approaches. For the assessment of the forest degradation Spectral Mixture Analysis was adopted using the forest remaining forest for the reference period of 2016- 2020.

For the forest inventory the total national level calculated number of sample plots was 2012 (404 clusters) out of which a total of 1526 plots (326 clusters) were surveyed. In Sindh the total calculated sample plots were 240 (48 clusters) out which 238 plots (42 clusters) were accessible and surveyed.

OpenForis Collect and MS Power BI software were used for data storage and processing. For tree height assessment Diameter-Height models were developed for most of the surveyed species. For aboveground tree biomass calculation existing local models developed by Ali et al 2017, 2019 and 2020 were used covering 63% of the surveyed tree species. For the remaining species the allometric equation developed by Chave *et al*. (2005) was used. Regarding carbon assessment all the IPPC recommended five carbon pools (Aboveground Biomass, Belowground Biomass, Deadwood, Litter, and Soil Organic Carbon) were considered for the overall carbon densities. For Emissions/ Removal factors for deforestation, forest degradation and enhancement the SOC pool was not considered due to insignificant changes during the reporting period of four years. The Emission/ Removal Factors were calculated for each forest type. Moreover, as per instructions of the NRO and also the IPCC requirement the Irrigated Plantations were only included in the assessment of the total carbon stock while for the estimation of the carbon emissions and removals the Irrigated Plantations were not included.

Total carbon stock in Sindh's forests was estimated as 42.45 million tons for 2020. The average carbon density in the forests was estimated as 143.2 t/ha. The highest carbon density was found in mangrove forests (239 t/ha), irrigated plantations (69 t/ha), subtropical broad-leaved forests (57 t/ha), riverine forest (42 t/ha) and dry tropical thorn forest (35 t/ha).

Total area of deforestation in Sindh was determined as 26,976 ha during the reference period of 2016-2020 with an average annual deforestation rate of 6,744 ha. The highest deforestation was found in riverine forest (24,036 ha) followed by tropical thorn forest (1,324 ha).

Total area under forest degradation in Sindh was estimated as 15,712 ha for the period from 2016 to 2020. The highest degradation was found in riverine forest (53%), followed by mangrove forest (25%) and tropical thorn forest (22%).

Total area of forest enhancement due to reforestation and afforestation in Sindh during 2016-2020 was estimated as 72,521 ha. The average annual enhancement rate was found as 18,130 ha for the period. The highest enhancement was found in mangrove forest (30,107 ha) followed by riverine forest (27,053 ha) and Tropical Thorn Forests (14,750 ha).

Total emissions from deforestation were estimated as 0.427 million tons of CO_2e between 2016 and 2020. The largest share of CO_2 emissions came from riverine forest (77%), followed by mangrove forest (9%), subtropical broadleaved scrub forest (8%) and tropical thorn forest (7%).

Total emissions from forest degradation were estimated as 0.27 million tons CO_2e during 2016-2020 and the total enhancement from improvement in canopy cover was estimated as 0.57 million tons CO_2e during this period. Thus, the net balance is removal of 0.30 million tons of CO_2e.

The total removal from enhancement due to reforestation and afforestation was estimated as 2.3 million tons of CO_2e between for the normal age of forests. For the four-year period (2016 to 2020) the total removals from enhancement were assessed as 1.167 million tons of CO2e, with 83% removals originating from Mangroves Forests, and 15 % from Riverine Forests.

Overall, a net balance of 1.04 million tons of CO_2e have been sequestered from enhancement due to afforestation, reforestation and improvement in forest cover during 2016 to 2020.

1. INTRODUCTION

1.1. Brief introduction of Sindh Province

Sindh is the third largest province of Pakistan and lies between 23° and 29° north latitude and 67° and 71° east longitude with a total area of 140,900 square kilometers. Sindh is bounded by the Thar Desert to the east, the Kirthar Mountains to the west and the Arabian Sea and Rann of Kutch to the south. According to the 2017 census Its total population is 47.9 million. Administratively, the province is divided in to 29 districts. Mean annual temperature is 26.1 °C while mean annual rainfall is 145 mm ("Pakistan Meteorological Department" 2022). Major part of the province is agricultural and range land with 31.7% and 28.1% respectively. Predominant Forest type is Mangroves Forest which is almost 3.5% while Riverain and Broadleaved Forest types occupies 1.4% of landmass (SUPARCO & FAO 2022).

1.2. Objectives of the carbon stock assessment

The sub-national GHG-Inventory aims to contribute to the implementation of the NFMS and to determine the performance against the national FREL and FRL. Specific objectives of the assignment are;

- To assess the forest carbon stock for the reference period of 2016-2020;
- To assess the carbon emissions from deforestation and forest degradation and removals from enhancement of carbon stocks for the reference period of 2016-2020;
- To provide sub-national figures for reporting on the national contribution to the mitigation of climate change;
- To access results-based REDD+ Finance for reducing emissions;

1.3. Process adopted for the GHG-Inventory

The Sub-National GHG-Inventory went hand in hand with the development of the Sub-NFMS by adopting the following stepwise process.

1.1.1. Adjustment and adoption of the national standards

1.1.1.1. Definition of Forest

The national definition of forest (2017) was adopted, which defines a forest as "A minimum area of land of 0.5 ha with a tree crown cover of more than 10 % comprising trees with the potential to reach a minimum height of 2 meters. This will also include existing irrigated plantations as well as areas that have already been defined as forests in respective legal documents and expected to meet the required thresholds as defined in the national definition for Pakistan."

1.1.1.2. Deforestation

As recommended by the National FREL/ FRL Submission (2020) the FAO (2015) definition of the deforestation was adopted for the current Sub-national GHG-Inventory. Deforestation is defined as "the direct human induced conversion of forest to non-forest (UNFCCC) or the permanent reduction of the tree canopy cover below the minimum 10% threshold" (FAO, 2015). A minimum mapping unit of 0.5 ha has been applied for the deforestation mapping (MoCC, 2020).

1.1.1.3. Definition of Forest Degradation

The national definition of forest degradation was developed and agreed during the development of the Sub-NFMS and Sub-National GHG-Inventory (2021). The national definition of forest degradation was developed as a result of detailed literature review and consultative process both at sub-national and national level. The forest degradation is defined as "Human induced long-term losses within forest persisting of at least four years or more due to changes in canopy cover i.e., open (11-30%), sparse (31-50%), medium (51-70%), dense (>70%) resulting in reduction in forest carbon stock and not qualifying as deforestation".

1.1.1.4. Methodology for assessment of Forest Degradation

Methodology for assessment of the forest degradation was developed and agreed during the development of the Sub-NFMS and Sub-National Green House Gas-Inventory of Forestry Sector (2021-22). The methodology is developed keeping in view the national definition of forest degradation. The methodology is based on Spectral Mixture Analysis (SMA), piloted for the first time in Pakistan. The SMA is a technique for estimating the proportion of each pixel that is covered by a series of known cover types. The SMA model decomposes proportional cover based on the reflectance of 'end-members' or pixels containing 100% of the land cover types of interest. Both the SMA and time series analysis are combined to detect forest degradation.

1.1.1.5. Activity Data

The data on the magnitude of human activities resulting in emissions or removals taking place during a given period of time (UN-REDD, 2013; MoCC, 2020).

1.1.1.6. Emission Factors

Emission factors for deforestation represent average net carbon dioxide (CO_2) emissions per hectare of land when forest land has been converted to non-forest land (MoCC 2020). Emission factors for forest degradation represent average net carbon dioxide (CO_2) emissions per hectare of land when a forest Emission factors for deforestation represent average net carbon dioxide (CO2) emissions per hectare of land when forest land has been converted to non-forest land (MoCC 2020). Emission factors for forest degradation represent average net carbon dioxide (CO2) emissions per hectare of land when a forest (remaining forest) converts from higher canopy cover class to a lower canopy class. For example, in the case of Pakistan when forest canopy cover converts;

1. From Dense to Medium, Dense to Sparse or Dense to Open;
2. From Medium to Sparse, Medium to Open or
3. From Sparse to Open

1.1.1.7. Forest Stratification

The national forest stratification agreed during the NFMS process was adopted with slight adjustment to the Sub-National level. Moreover, the forest stratification (forest types) map/ boundaries were also reviewed and adjusted (Table 1).

Table 1: National Forest type stratification with adjustments

Climate Zone	Ecological Zone		Adjustments made during the Sub-NFMS process
	Main Ecological Zone/ Forest Type	Sub-Ecological Zone/ Forest Type	
1. Tropical	1.1 Littoral and swamp forest	1.1.1 Mangroves	
	1.2 Tropical dry deciduous		
	1.3 Tropical thorn forest		
	1.4 Riverain forests		
2. Sub-Tropical	2.1 Sub-tropical broad-leaved evergreen forests	2.1.1 Montane sub-tropical scrub Forests	Combined as scrub forests
		2.1.2 Sub-tropical broad-leaved forests	
	2.2 Sub-tropical pine forests		
3.Temperate	3.1 Moist Temperate Forests		
	3.2 Dry Temperate Forests	3.2.1 Montane Dry Temperate Coniferous Forests	Combined Dry Temperate Coniferous, Dry Temperate Broad-leaved Forests and Northern Dry Scrub Forests as Dry Temperate Forests
		3.2.2 Dry temperate Juniper and Chilgoza Forests	
		3.2.3 Dry Temperate Broad-leaved Forests	
		3.2.4 Northern Dry Scrub	
4. Alpine	4.1 Sub-Alpine Forests		
	4.2 Alpine Scrub		
5. Plantation	5.1 Linear Plantations	5.1.1 Road side plantations	
		5.1.2 Railway side plantations	
		5.1.3 Canal side plantations	
	5.2 Irrigated Plantations		

1.1.2. Field and Satellite Based Inventories

For Satellite Based Inventories Landsat-8 imageries were acquired for the reference years 2016 and 2020. A total of 130 Landsat-8 images (65 for reference year 2016 & 65 for 2020) were downloaded from the USGS Earth Explorer web portal using https://earthexplorer.usgs.gov. The forest stratification maps developed during the NFMS/ FREL 2020 were updated and adopted.

For forest inventory the national protocols were reviewed and updated keeping in view the sub-national level context. Number and location of old survey plots were compiled from the NFMS/ FREL reports 2020 and Provincial Carbon Stock Assessment reports of KP, GB and Punjab. The total national level calculated number of sample plots was 2012 (404 clusters) out of which a total of 1526 plots (326 clusters) were surveyed. In Sindh the total calculated sample plots were 240 (48 clusters) out which 238 plots (42 clusters) were accessible and surveyed. Details of the methodologies adopted for the SLSM and Forest inventories are explained in the following sections.

2. ESTIMATION OF FOREST CARBON STOCK AND EMISSIONS

2.1. Area Covered

The current GHG-Inventory Report covers the total area of the Sindh Province, which is 140,900 km².

2.2. Carbon Pools and Gases

The National FREL Report of Pakistan (2020) has covered only CO_2 which is the major GHG emitted from
The National FREL Report of Pakistan (2020) has covered only CO_2 which is the major GHG emitted from deforestation and forest degradation. The current GHG-Inventory also covers only CO_2 as estimates of other GHG gases are not available at the moment. The current report includes all the five carbon pools for the total carbon stock; Above Ground Biomass; Below Ground Biomass; Deadwood; Litter and Soil Organic Carbon (SOC). However, the SOC was excluded from the Emission/ Removal Factors for deforestation, forest degradation and enhancement due to the reason that changes in SOC over the reporting period of four years are insignificant. As per IPCC guidelines the recommended period for assessment of SOC is more than 20 years (IPCC, 2006).

2.3. Activities Covered

The National FREL of Pakistan has covered only deforestation. However, there is an improvement in the current assessment as it covers deforestation, forest degradation and enhancement of forest carbon stocks. According to the national definition of forest (2017) a forest is "A minimum area of land of 0.5 ha with a tree crown cover of more than 10 % comprising trees with the potential to reach a minimum height of 2 meters. This will also include existing irrigated plantations as well as areas that have already been defined as forests in respective legal documents and expected to meet the required thresholds as defined in the national forest definition of Pakistan" (MoCC, 2020). However, as required under IPCC GPG guidelines irrigated plantations (IPs) were not included in estimation and assessment of carbon emissions and removals under this assignment. The Irrigated Plantations were only included in the total carbon stock of the province for the years 2016 and 2020.

Deforestation refers to "the direct human induced conversion of forest to non-forest (UNFCCC) or the permanent reduction of the tree canopy cover below the minimum 10% threshold (FAO, 2015) as provided in the National FREL of Pakistan (2020). On the other hand, Forest Degradation refers to "Human induced long-term losses within forest persisting of at least four years or more due to changes in canopy cover i.e., open (11-30%), sparse (31-50%), medium (51-70%), dense (>70%) resulting in reduction in forest carbon stock and not qualifying as deforestation" (MoCC, 2021).

2.4. Consistency with National GHG Inventory

In the context of national greenhouse gas inventories, it is mandatory for Non-Annex-I countries to report the CO_2, CH_4 (Methane) and N_2O (Nitrous oxide) emissions. Carbon dioxide must always be included in REDD+ accounting. The CH_4 emissions are normally emitted from the forests growing in wet organic soils. Conversion of these forests through drainage is not an acceptable practice in scope of REDD+. Nitrous oxide emissions take place when biomass is burned, fertilizer is applied or nitrogen fixing trees are planted in the forest, but these activities except fire are rare in Pakistan. Incidences of forest fire have increased in the recent years but there is no data on the quantum of forest degradation caused by forest fire. However, future carbon stock assessments and GHG-Inventories can take into account the emissions caused by forest fire.

3. DATA, METHODOLOGY AND PROCEDURE

3.1. Mapping of Activity Data for Deforestation

Activity data refers to the data on the magnitude of human activities resulting in emissions or removals taking place during a given period of time (UNREDD, 2013). The current carbon stock assessment covers activity data on deforestation, forest degradation and carbon stock enhancement. The methodology used for generation of activity data is given as follows.

Supervised machine learning algorithms were used for the Land cover change analysis. Free and Open Source Softwares and imagery were used to achieve the objective. Collect earth was employed to visually interpret the systematic sample plots generated. ROIs were generated from these interpreted plots and training sets were defined. A specific algorithm was used to classify the images to extract the LULC of reference years 2016 and 2020. Post processing was conducted for the noise removal. Accuracy assessment and change maps were developed for the national as well as sub-national level. Following main steps (as recommended under the NFMS, 2020 and FRL/ FREL, 2020) were adopted.

Process 1: Satellite Imagery Acquisition and Processing

Activity data mapping was based on the LULC classification using Landsat imagery 8 for the reference years of 2016 and 2020. Atmospherically corrected and cloud free (less than 10%), Landsat-8 L2SP (Collection 2 level 2 and Tier 1 Science Product) images were downloaded from the from USGS Earth Explorer web portal using https://earthexplorer.usgs.gov. Total, 130 Landsat-8 images (65 for reference year 2016 & 65 for 2020) were downloaded. Landsat-8 OLI image bands (2, 3, 4, 5, 6, 7) were stacked using QGIS, Open-Source software, to generate composites (natural color, VNIR, SWIR etc.) (Table 2). Province wise mosaics were developed in QGIS for using in classification (Table 3).

Table 2: Details of the Landsat-8 images downloaded for one Year

Path	Rows										Total
	34	35	36	37	38	39	40	41	42	43	
147		1	1								2
148		1	1		1						3
149	1	1	1	1	1	1	1				7
150	1	1	1	1	1	1	1	1	1	1	10

151	1	1	1	1	1	1	1	1	1	1	10
152		1	1	1	1	1	1	1	1	1	9
153					1	1	1	1	1	1	6
154					1	1	1	1	1	1	6
155						1	1	1	1	1	5
156						1	1	1	1	1	5
157						1	1				2
Total	3	6	6	4	7	9	9	7	7	7	65

Table 3: Province wise Landsat-8 images processed for Classification

Province	Images for 2016	Images for 2020
AJ&K	4	4
Balochistan	33	33
Gilgit Baltistan	12	12
Khyber Pakhtunkhwa	13	13
Punjab	17	17
Sindh	14	14

Process 2: Systematic Sampling Design and LULC Interpretation

Systematic sampling grids were generated to cover the territory of the Islamic Republic of Pakistan for the sampling for IPCC Land Use classes to be used for preliminary wall-to-wall land use map preparation and forest inventory design. The systematic grids and the sample plots were created using Free and Open-Source Data and Open-Source Tools as part of the desktop-based Satellite Land Monitoring System (SLMS) workflow for the implementation of the Sub-NFMS and Forest Carbon Stock Assessments.

Systematic 10'x10' or 5'x5' sample grids were generated to collect the training and validation samples for classification. Visually interpretation for IPCC Land Use Classes (Forest, Cropland, Grassland, Wetland, Settlement, Other land) was done using very high-resolution (VHR) satellite imagery from google earth, False color composites of Landsat 8 and Sentinel 2 and their time series NDVI analysis available in FAO's OpenForis Collect Earth tool. For Forest plots, sub-plots with tree cover were counted to estimate tree cover in the plot. Observable disturbances in the plot were also interpreted in the VHR images, which mainly include: Logging, Fire, Grazing, Landslide, Tree Plantation, Shifting Cultivation, Construction and others. Total 3,096 visual squared plots with 50x50-meter dimensions were sampled and visually interpreted to get better representation for all the major land use and cover types.

Denser sampling grids were applied for the smaller provinces, AJK to ensure a sufficient number of plots over all the main land use and cover categories (Table 4). Because of its large area, Balochistan province was sampled with the lowest density. Five GIS analysts/ operators were involved in the original interpretation process for different years of assessment, and interpretation results were cross-checked by two GIS experts as well as the forestry experts in the team. All the conflicting observations between the different years were harmonized by supervisors.

Table 4: Province wise number of interpreted plots and plots density

Province Name	10x10 Interpreted Plots	5x5 Interpreted Plots	2.5x2.5 Interpreted Plots	Manually added plots	Total interpreted plots
AJ&K	48	194		55	249
Balochistan	1138			762	1900
Gilgit Baltistan	358			-	358
Khyber Pakhtunkhwa	246			184	430
Punjab	701			405	1106
Sindh	459			12	471
Total	**3096**			**1418**	**514**

To increase the samples of those classes that have low number of sample than others, manual training samples from the systematic grids were added to get better representation for all the major land use and cover types. In addition, to improve the classification results, a set of manual training samples from the systematic grids were added where misclassification was observed to forcefully classify as desired class. About 1,418 samples were also included from denser grids to get the better classification results.

Process 3: Designing Sample Set for Image Training

Satellite image classification was carried out using the Google Earth Engine (GEE) Plugin in QGIS. Region of Interest (ROI) polygons were generated using the interpreted plots as 'seeds' using region growing algorithm. The minimum area of ROI was set 2 pixels whereas maximum area was 10 pixels to generate the ROIs. These ROIs basically delimited the spectral signature information against each sample using the SCP Plugin. A representative training set sample with regions of interest (ROI) has been selected by the operators for training image pixels for LULC classification. 70% of the generated ROIs were used as training sample and 30% for the accuracy assessments.

Process 4: Image Classification

Random forest (RF) algorithm was adopted for image classification. The GEE plugin in QGIS was used to carry out the classification process iteratively. The preliminary classification result showed a number of obvious errors, partly due to the lack of training samples in some land cover classes. To address this problem manual training samples were added for the classes (Forest, Crop, Water and settlements) because these classes had a low number of training samples in the interpretation of 10'x10' grids. The issue of misclassified shadow pixels as forest or water in mountainous region was addressed by adding a new class "Shadow". The "Shadow" class was then merged with the relevant cover class after verification from the VHR images. Moreover, manual training samples were added at locations where misclassifications were observed to forcefully classify as the desired class. Few training samples which seemed problematic were deleted to get the better classification results. As the systematic 10'x10' grids were interpreted using Google Earth Imagery and Landsat 7 and 8 and there was the possibility of incorrect interpretation compared to the downloaded images. Each sample was carefully checked by visualizing with different band combinations and spectral signature and deleted the few problematic samples. The class of the few training samples was changed (grasses to other-land and vice versa) to the appropriate class after visualizing the satellite image with different band combinations and spectral response.

Process 5: Post Classification Processing

Post classification processing was applied to remove noise such as 'salt and pepper' effects of individual classified pixels and to rectify the misclassification. This was done by "sieving" isolated pixels and replacing them with the classification of surrounding majority class pixels. The threshold for sieving was set to two pixels for one-time Land Use Land cover assessments. The classification results were also compared to historical LULCs; 1). by sharing the GIS data with the concerned GIS experts and focal points of provincial forest departments and getting their input, and; 2). by using Sentinel data as reference for the improvement in accuracy. In addition, feedback from provincial forest departments was obtained during validation consultations using field inventory data and experts' ground knowledge. Based on this information, misclassifications in the land use and land cover classification maps were identified and corrected manually. For the deforestation map, a minimum 5-pixel threshold was applied and the minimum mapping unit for the deforestation and enhancement was defined as 0.5 ha.

Process 6: Accuracy Assessment and Area Estimation

Accuracy assessment and area estimation of the LULC map classes were conducted using the sample of reference observations of the study area. The basic assumption is that the mapped areas of land cover are biased because of image classification errors, which are identified by comparing the map to a sample of reference observations. 30% random samples were selected from all samples of the reference study areas to measure the accuracy of the classified images for both years (2016 and 2020). The SCP post-processing tool "Accuracy" was used to obtain the result and generate the standard error matrix for LULC analysis. The area estimation of each IPCC class was generated using the classification report tool. These areas can be biased and may not correctly represent the true land cover due to classification errors. In order to adjust these areas, the standard guidelines of REDD+ were followed using referenced samples, that represent accurate estimation of the cover areas of each class. The forest areas of each province were measured by keeping in mind the standard definition of the forest and were further validated with the support of inventory data and feedback from the representatives of provincial forest departments.

Process 7: Land Use Change Assessment

Deforestation activity data generation is based on the visual plots interpreted for the LULC statistics and analyzed with GIS raster analysis operations. A hotspot layer, indicating the potential locations for deforestation, was produced in order to calculate statistics regarding changes from forest to other land use categories.

For the accuracy assessment and change matrix, systematic interpreted plots (over 3,096 plots) and some additional randomly sampled visual interpretation plots (1,418 plots) were investigated. The deforestation area proportions (percentages) by forest types were derived by using the hotspot maps.

For accuracy assessment and permanence check, the final maps were interpreted and crosschecked with the support of experienced foresters in the WWF-Pakistan team and feedback from the representatives of concerned provincial forest departments. Pixel based change detection was conducted using change matrix with spatial distribution. Sieve tool with 5 pixels was applied on the deforestation raster to extract the rate of deforestation and enhancement at the national as well as sub-national level.

3.2. Mapping of Activity Data for Forest Degradation

The methodology for mapping of activity data on forest degradation is based on the Spectral Mixture Analysis (SMA) and has been piloted for the first time in Pakistan. The Spectral Mixture Analysis (SMA) is a technique for estimating the proportion of each pixel that is covered by a series of known cover types. In other words, it seeks to determine the likely composition of each image pixel. The SMA model decomposes proportional cover based on reflectance of 'end-members' or pixels containing 100% of the land cover types of interest. Both the SMA and time series analysis are combined for detecting forest degradation.

3.3. Mapping of Activity Data for Enhancement of Carbon Stock

Enhancement of carbon stock includes increase in forest area through afforestation and reforestation or increasing the density of forest cover so that it changes from a lower density class to a higher density class. Increase in forest area through mapping of plantations raised in provinces was assessed using the following methodology.

Satellite images taken on the earth's surface are analyzed to identify the spatial and temporal changes that have occurred naturally or manmade. Real-time prediction of change provides an understanding related to the land cover. Province wise Pixel based change analysis of Land use land covers of 2016 and 2020, developed using the machine learning algorithm Random Forest (RF) using the GEE Plugin QGIS software environment has been done to map the Deforestation and Enhancement. Deforestation and enhancement areas were computed and mapped using a sieve of five Landsat-8 pixels, which implies deforestation/enhancement mapped with less than five pixels was considered noise and merged into the adjacent class. According to the guidance provided by the National REDD+ Project officials and REDD+ guidelines, the minimum mapping unit for deforestation and enhancement was predefined as 0.5 ha.

3.4. Emission Factors for Deforestation

Emission Factors for deforestation were developed by converting the carbon stock density value (C ton/ha) of each forest type to CO_2 equivalent using an expansion factor of 3.67. Carbon stock values for different forest types were determined using the forest inventory data at sample plot level collected during the current assessment. The carbon density value included aboveground biomass of trees and shrubs, belowground biomass, dead wood, litter and soil organic carbon. However, the EFs/ RFs did not include the SOC. In case of Pakistan, data on non-forest land uses is not available. The emission factors were developed on the basis of the difference in the amount of carbon in carbon pools of the forest and non-forest land uses excluding soil organic carbon. This was mainly due to the reason that accumulation of soil organic carbon takes considerably long time and there may not be a significant difference in the soil organic carbon between forest and non-forest land uses especially during the reporting period of four years (2016-2020). Moreover, changes in soil organic carbon (SOC) largely depend on the type of land management and could be accounted over a period of 20 years in scope of the GHG-I accounting (IPCC, 2006; MoCC, 2020). Due to the same reason the FREL/ FRL Submission 2020 also did not account for the soil organic carbon. Regarding conversion of biomass to carbon the default IPCC fraction (0.47) was applied.

3.4.1. Sampling Design

The sampling scheme was designed using the stratified two-phase sampling approach with integration of the SLMS process. During the first phase a systematic grid of 10'x10' was generated which was used for visual interpretation of land use and forest cover analysis. During the second phase 10'x10' grid was adjusted to 5'x5'/2.5'x2.5'/1.25'x1.25 according to the provincial level forest mask to determine the number of sample plots and accessibility criteria. The stratification was done on the basis of forest types using the forest mask (2012) and the forest type boundaries developed during the pilot NFI 2018. The two-phase sampling process, the number of sample plots calculated and stats applied during the sample plots calculations are given in Table 5 below and Figure 1. The sample design included the following steps.

- Systematic generation of 10' x 10' grids (at national level)
- Adjustment of grids to provinces and forest types (5' x 5', 2.5' x 2.5', 1.5' x 1.5'). The 10' x 10' grids, when did not fit according to the number of sample plots, the forest types then the girds were adjusted accordingly to (5' x 5', 2.5' x 2.5', 1.5' x 1.5').
- Calculation of province and forest type wise number of sample plots on the basis of mean biomass and standard deviation using the Win Rock Sample Plot Calculator. The mean biomass and standard deviations were taken from the NFMS data 2018. Forest types were used as forest strata and the province and forest type wise areas were taken from the 2012 forest mask and forest statistics.
- Plotting of sample plots on maps (province wise and forest wise). Used the 2012 forest mask (cover map) for laying out and mapping of the sample plots.
- Repeating previous inventory plots. The sample plots of 2018 forest inventory as well as the provincial forest inventories in KP, GB and Punjab were repeated.
- Development of province wise, district wise and cluster wise maps of sample plots.

Table 5: Province wise number of sample plots

Forest Type/Strata	KP		GB		AJK		Punjab		Sindh		Balochistan		Total	
	Plot	Cluster	Plot	Cluster	Plot	Cluster	Plot	Cluster	Plot	Cluster	Plot	Cluster	Plot	Cluster
Sub-Alpine	15	3	55	11	15	3	0	0	0	0	0	0	85	17
Dry Temperate	91	18	410	82	20	4	0	0	0	0	200	40	721	145
Moist Temperate	225	45	0	0	150	30	15	3	0	0	0	0	390	78
Pine	100	20	0	0	35	7	135	27	0	0	0	0	270	54
Scrub	15	3	0	0	25	5	85	17	15	3	15	3	155	31
Thorn	15	3	0	0	0	0	20	4	55	11	15	3	105	21
Riverine	0	0	0	0	0	0	15	3	60	12	0	0	75	15
Mangrove	0	0	0	0	0	0	0	0	60	12	15	3	75	15
Irrigated Plantations	0	0	0	0	0	0	100	20	50	10	0	0	150	30
Total	461	92	465	93	245	49	370	74	240	48	245	49	**2,026**	**406**

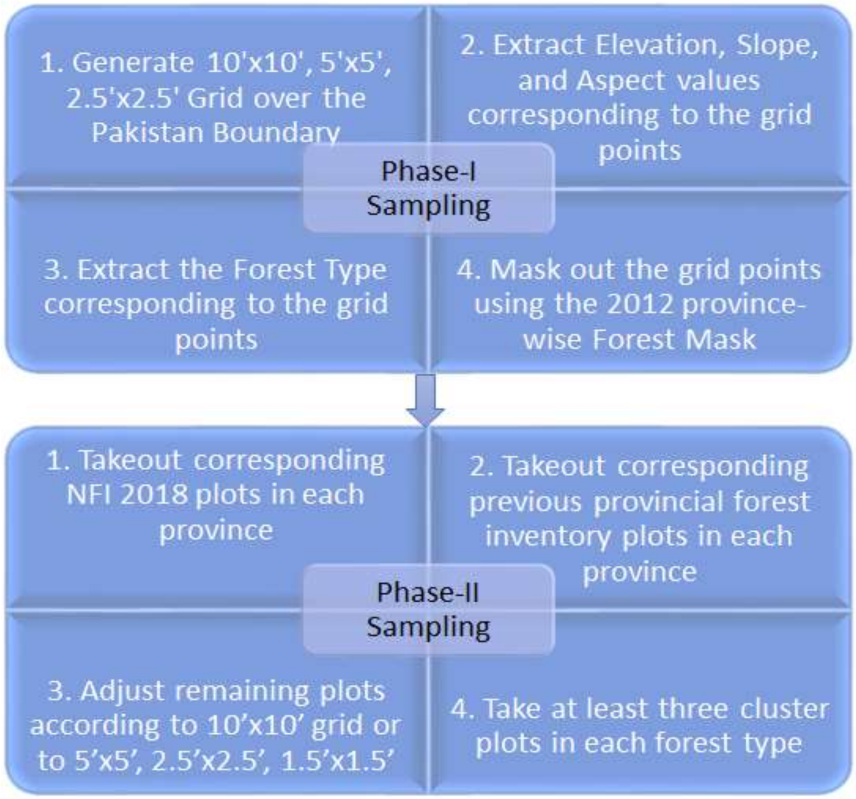

Figure 1: Stratified two-phase sampling process with integration of the SLMS process

Cluster sample design as adopted during the pilot National Forest Inventory, 2018 was followed to have consistency with previous inventory (MoCC, 2020). A cluster sample plot comprises of five subunits or sub-plots; a Primary Sub Unit (PSU) situated at the center of the cluster and four Secondary Sub Units (SSUs) located at the four corners 200 meters apart from each other (Figure 2). Each sub-unit or sub-plot comprised of three concentric circular plots; 1). A plot with a radius of 17.84 meters (~1000 m^2) for measuring all living trees and standing deadwood stems with DBH1 above 5 cm; 2). A sub-plot with a radius of 5.64 meters (~100 m^2) for counting seedlings and measurement of shrubs, and; 3). A sub-plot with a radius of 0.56 meter (~1 m^2) for measuring and taking above-ground non-tree, litter and soil samples (Figure 2).

The inventory protocol for mangrove forest is different from the inventory of normal forest (Figure 3). Each cluster sample consists of five Sub-units; a Primary Sub-Unit (PSU) situated at the center of the cluster and four Secondary Sub-Units (SSUs) situated at the four corners of the cluster and 50 meters apart from each other. Each Sub-Unit has three concentric circular plots; A sub-plot with a radius of 8.92 meters (half the size of the radius of the normal sub-unit) for measuring trees with DBH more than 5 cm, and subplots with radius of 5.64 m for shrubs and regeneration and subplot of 0.56 m radius for measuring pneumatophores and litter. A soil sample is also extracted from 1 m depth in the center of the plot to determine soil organic carbon in the ecosystem. Complete workflow of the forest inventory is given in Figure 4.

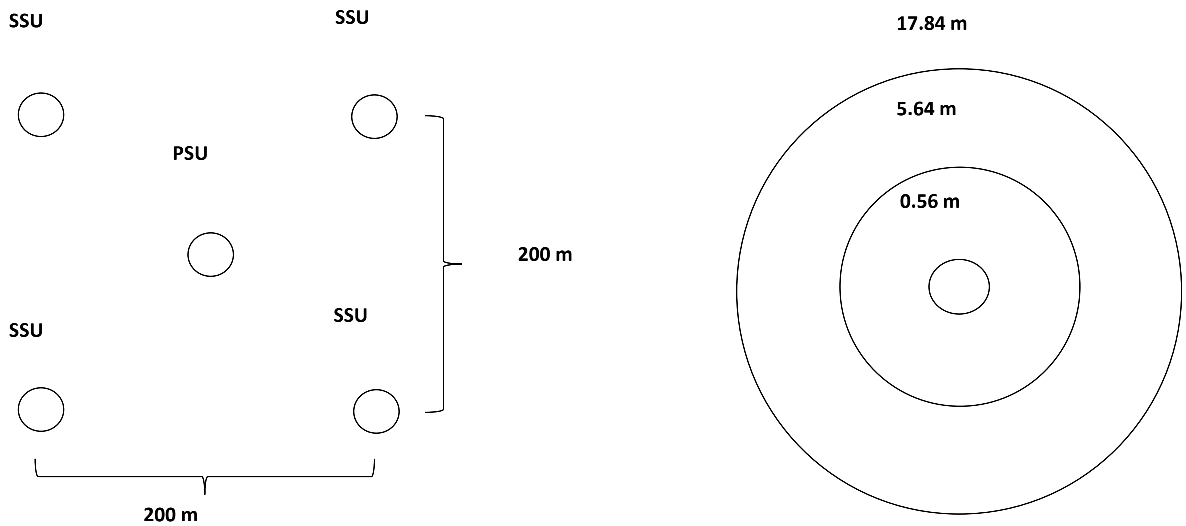

Figure 2: Clustered primary and secondary sample units (plots). Source: NFMS, 2020

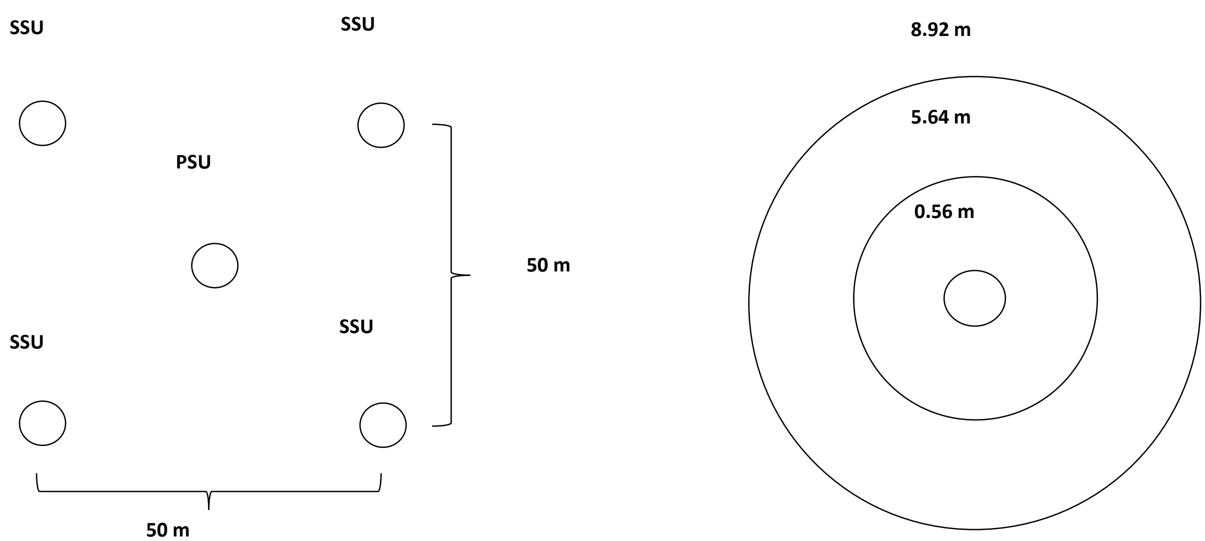

Figure 3: Clustered primary and secondary sample units (plots) for mangrove forests. Source: NFMS, 2020

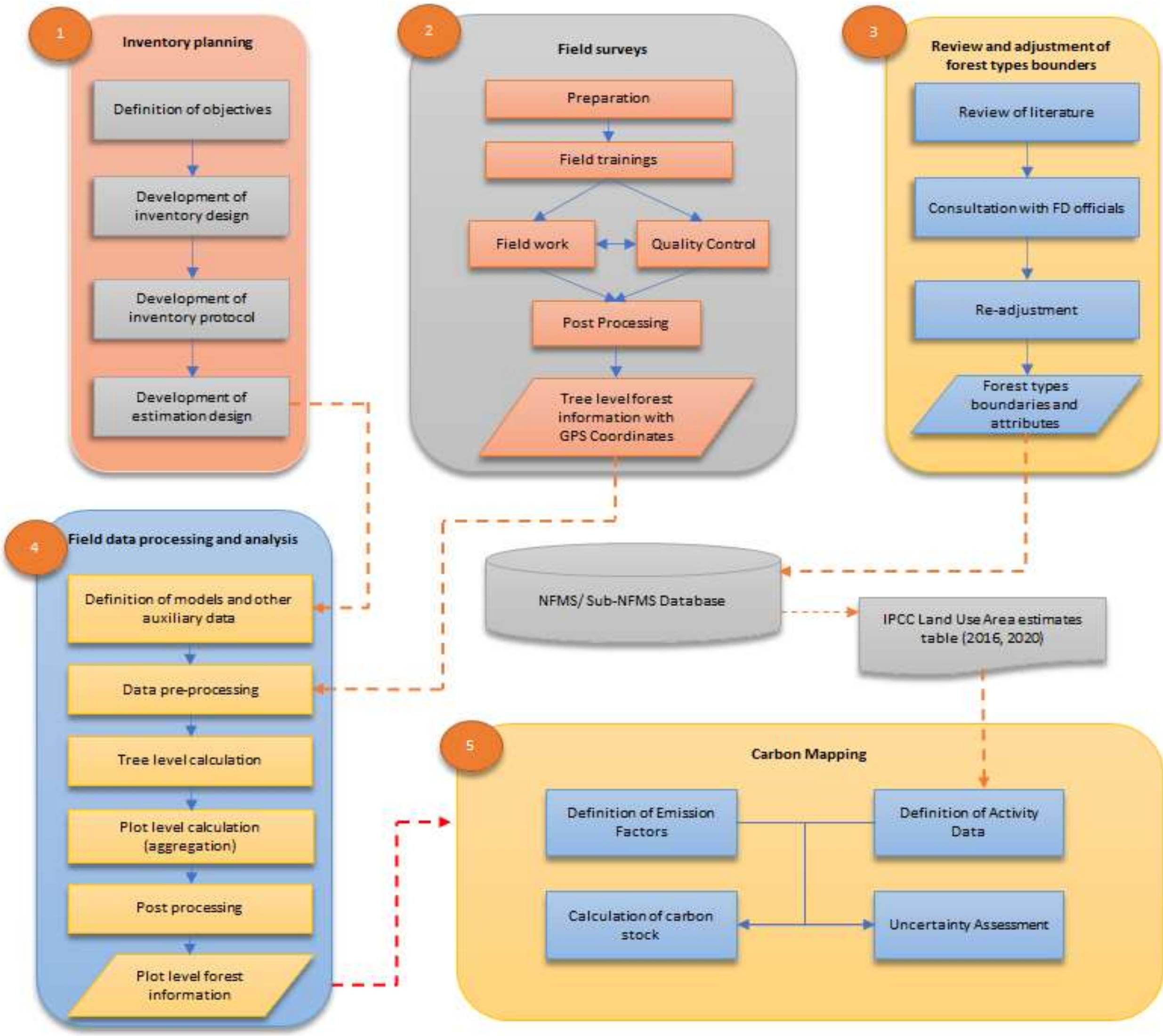

Figure 4: Forest Inventory Workflow (Source: adopted from NFMS-MRV Report, 2020)

3.4.2. National Forest Inventory Protocol

The National Forest Inventory Protocol were mainly adopted from the National Forest Inventory Manual developed during the NFMS development in 2018-2020 with minor adjustments according the new situation. The protocol mainly consisted of; 1) formation of field teams (team leader and members, and their duties); 2) Proper field measurements and collection of samples during the field work (general information of the plot i.e., coordinates, elevation, aspect, slope, disturbance etc., measurement of tally trees, measurement of sample trees, measurement of dead wood, litter, shrubs and regeneration, and soil, and taking samples for lab test); 4) Quality Control and Quality Assurance during the forest inventory as well as the post inventory data entry, cleansing and processing phases.

All carbon pools i.e., aboveground biomass (trees and shrubs), belowground biomass, dead wood, litter and soil organic carbon were measured during the current MRV campaign. Following protocols for measurements were considered during the forest inventory. Revised Forest inventory manual 2022 is given as Annex-8 (provided as separate file).

- Cluster Information (Primary Sampling Unit)
    - Time log (starting time and reaching time)
    - Coordinates of waypoints
    - GPS coordinates of PSU location
- Plot information and Land Use
    - Measurement Time Log
    - GPS Coordinates
    - Terrain Parameters (Slope in %, Aspect, Erosion, Main site type (mineral soil, peat lands, wetlands))
    - Land Use type (forest land (and type), cropland, grassland, settlements, wetlands, other land)
    - Canopy cover (<10%, 10-30%, 31-50%, 51-70%, and >70%)
    - Disturbances
    - Land Use and Land Use Change (Deforestation, Forest Degradation and causes)
- Measurement of tally trees
    - All trees with DBH-1 above 5 cm are measured from the sample plots with radius of 17.84 m (8.92 m plot in case of mangrove forests).
    - Species and DBH-1 (at 1.3 meters). In case of anomaly at 1.3 m the DBH was measured slightly above that point. In case of forked tree below DBH, two trees were considered.
    - In Mangrove Forest diameter at 1.3 m and 30 cm above the ground within 8.92 m radius plot were measured.
    - Broken top or not. Broken top trees were not selected as sample trees.
- Measurement of sample trees
    - Sample trees were selected from all measured alive trees by selecting every 5th tree starting from tree no. 1.
    - If the selected tree had a broken top or had some anomaly at the breast height, it was not selected as sample tree. In that case the next tree in order was selected as sample tree, however, the next sample tree was selected based on the same order.
    - The sample trees were measured for second DBH with breast height at 1.37 meters, top height, bole height, and in case of leaning trees also base length for both top height and bole height.
- Dead wood measurement
    - Species Name
    - Category (Standing Dead Wood, Down Dead Wood and Stump)
    - Standing Dead Wood:
        - All the standing dead trees with DBH1 measured at 1.3 m height greater than 5 cm were enumerated within the full 17.84 m plot.
        - DBH1, top height and decomposition state were recorded for all the standing dead trees.
        - The specific decomposition stage classes for standing dead wood are:

      - 1) Tree with branches and twigs and resembles a live tree (except for leaves);
      - 2) Tree with no twig, but with persistent small and large branches;
      - 3) Tree with large branches only;
      - 4) Bole (trunk) only, no branches
  - Downed Dead Wood:
    - Downed branches and stems of trees and brush with minimum DBH above 5 cm, which were fallen and lied on or above the ground were measured from the 17.84 m.
    - Only the proportions of dead wood stems and their fragments lying inside were measured.
    - The measurements included the length (m) inside the plot and diameters (cm) at the two ends of the wood or fragment particle.
  - Stumps: All the stumps with diameter above 5 cm were enumerated within the full 17.84 m plot (8.92 m plot in case of mangrove forests).
    - The stump diameter was measured in two diagonal directions, its lowest and highest heights with a measuring tape from the level of seeding point.
    - For dead wood following decomposition levels were assessed;
      - 1) Sound (blade does not sink or is bounced off).
      - 2) Intermediate (blade partly sinks into the piece of wood or there has been some wood loss).
      - 3) Rotten (blade sinks well into the piece, there is extensive wood loss and the piece is crumbly).
  - DBH/Diameter 1 (x.x cm): The first end diameter measurement for downed deadwood, stump diameter or DBH at 1.3 meters for standing trees.
  - Diameter 2 (x.x cm): The second end diameter measurement for downed deadwood or stump.
  - In Mangrove Forest diameter at 1.3 m and 30 cm above the ground within 8.92 m radius plot were measured.
  - Tree height / length (x.x m): Tree height or particle length measured in meters
  - Standing tree, base length (x.x m): The standing dead tree base length is only measured for heavily leaning sample trees. Tree base length is the distance on the ground from the base of the tree to the top of the trunk.
  - Standing tree broken top (1/0): All the standing dead trees were marked as broken top or not. 1 was for broken top, and 0 was for normal.
- Measurement of litter and shrubs
  - Shrubs were measured through destructive sampling in the 5.64 m plot. Shrubs were cut, weighed and recorded. The shrubs were then chopped and a certain portion was taken, weighed, packed and labelled as sample for lab testing (for determining oven dry weight.
  - In case of mangroves dwarf mangroves shrubs less than 5 cm diameter at collar were collected from the 6.64 m plot using the above method.
  - Non-tree biomass Litter, herbs, grasses and soil biomass are extracted from the 0.56 m sub-plots.
  - The litter layer is defined as include all dead organic surface material on top of the mineral soil.
  - All the leaf litter and wood litter less than 5 cm in diameter within the subplot were collected and their fresh weights determined in the field with a weighing balance.

  - The sample weighted on site after excluding the plastic bag weight.
  - A sub-sample for plot was taken, weighed, placed in a zip-locked polythene bag, labelled and then taken to the laboratory to determine the oven dry mass and carbon content.
  - Pneumatophore density of Avicennia *marina* was determined by counting their numbers and taking their fresh weight in the 1 m^2 plots established for the litter layer.
- Measurements for soil organic carbon
  - Due to time constraint soil samples were collected only from the PSUs in each cluster.
  - For Soil Organic Content collected the soil samples using the auger/ chisel and put it in a clean bucket.
  - Samples from the different depths were placed in separate buckets.
  - Mixed the soil in the bucket thoroughly and took sub-samples, put in a sampling bag.
  - The sample was weighed and labelled with sample ID and fresh weight.
  - For bulk density the soil sample was taken using a cylindrical metal sampler of 5 cm diameter and 5 cm length.
  - The core was driven to the desired depth (0 – 10 cm, 10 – 20 cm and 20 – 30 cm) using a hammer and the soil sample carefully removed to preserve the known soil volume existed in situ using the soil knife.
  - Volume and fresh weight of the soil collected in the core from each depth were recorded.
  - The soil sample was then transferred into a clean sampling bag without spilling it and label the sample bag clearly.
  - Filled in soil sample information sheet including the details (name of sample collector, address, date, area and location).
  - Packed the samples in clean bags and took to the laboratory for analysis.
  - In mangrove forests Soils samples (loose soil) were taken from 0-10 cm, 10-20 cm, 20-30 cm, 30–50 cm, 50–100 cm.
  - Samples were packed, labelled and sent for lab testing.
- Plot photos
  - Photographs at each PSU and SSU were taken towards the compass direction in North, East, South and West from the plot center.
  - The corresponding Photo number/ID/ file name with other site characteristics were noted in the field sheets.

As recommended in the revised forest inventory manual both hot and cold checks were performed. The hot checks consisted of spot visits by the WWF-Pakistan’s provincial coordinators and sometimes the concerned provincial REDD+ focal persons to the inventory sites and checked the data collection procedures in the field. For the cold checks the team visited the forest inventory teams, randomly picked 10% clusters and re-measured the tree parameters and dead wood in the PSUs of the selected clusters. The data was entered in OF Collect entry sheets and the error was assessed using the Power BI software using the formula below:

$$Measurement\ error\ (\%) = \frac{(biomass\ before\ corrections - biomass\ after\ corrections)}{biomass\ after\ corrections} \text{ X } 100$$

3.4.3. Data Storage and Processing

The entire process of data storage and processing consisted of three phases: I) data acquisition, II) data entry, III) data cleansing and IV) data analysis. Measured and/or estimated data was recorded in the field on the field sheets during the NFI (I. Field data acquisition). Duly filled in field sheets were delivered to the office where the recorded values were crosschecked and entered into the OF data management software (II. Data Entry). The software runs several validation rules against the entered data and indicates erroneously entered or missing values. Once the (per cluster) data sets were complete, they were promoted to the data cleansing stage (III. Data Cleansing). Consequently, these were exported to PBI for a systematic data cleansing. In PBI the values were systematically checked again for completeness and plausibility, e.g., value ranges, conspicuous values, etc. Data Storage and Processing report is given as Annex-9 (provided as separate file).

Following the data entry and cleansing procedures of NFI field data in OF, the ("analysis ready") data is exported as data tables in MS Excel format (IV: Data Analysis). The data processing workflow is illustrated in Figure 5. The entire workflow can be summarized as under.

- Measurement/estimates values were recorded on field sheets.
- Field sheets data were entered in OpenForis Collect.
- Data was controlled (cross-checks), validated (plausibility) and checked for completeness.
- Complete data sets were promoted to "data cleansing" and exported to PBI.
- In PBI, systematic data cleansing was applied, considering completeness and plausibility.
- Cleansed data was promoted to "data analysis" and exported to PBI for analysis.
- Data issues (i.e., outliers, etc.) observed during data analysis result in data sets were demoted to "data cleansing".

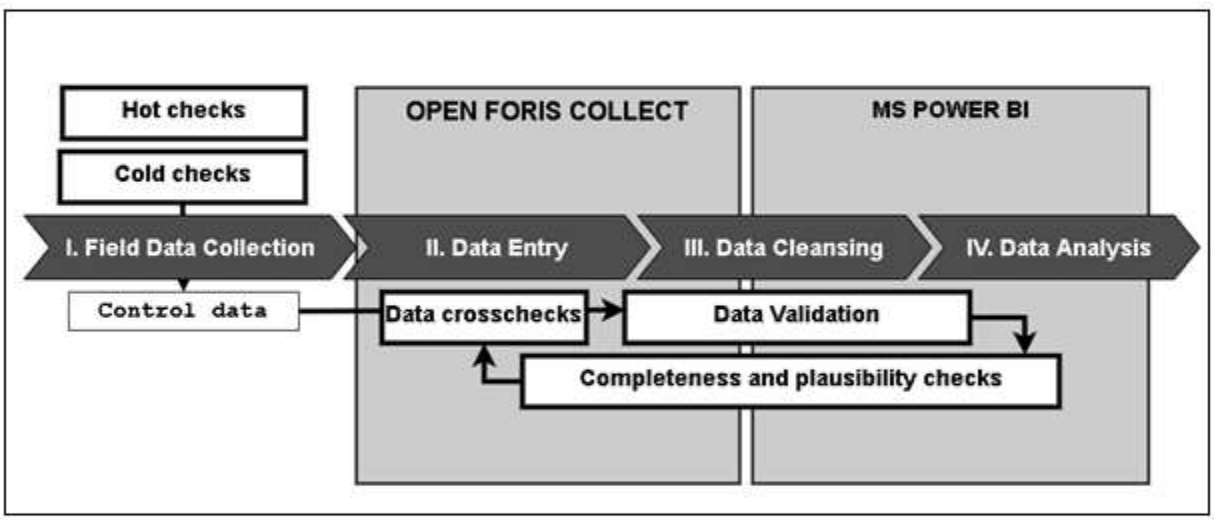

Figure 5:Data storage and processing workflow

3.4.4. Diameter-Height model development

Initially the Diameter-Height models were developed for species, genera or species groups having more than 30 height measurements. Species or genera having less than 30 height measurements were grouped as other coniferous species and other broadleaved species (for each province). These models were developed using excel spreadsheets based on R values (Table 6). The initially developed models (representing the DBH-H relationships per species, genera or species group) were then adjusted and used to determine the missing tree-height values for each species. For the PBI analysis, the performance of available Diameter-Height models was assessed visually (Table 7). For some species like Populous euphretica, Tamarix dioca and Ziziphus mauritiana the diameter-height models developed by Ali, 2017 and Ali, 2019 were adopted. The diameter-height models developed during the current assignment depend on the diameter and height range of the sample trees and may vary with broader range. These models should be updated and improved with more samples and broader diameter-height range of sample trees.

Table 6: Diameter-Height Models developed during initial stage

Species	Range of DBH (cm)	Range of height (m)	Number of sample trees	Model with R^2 value
Acacia modesta	5-46	2-11.6	131	H = 3.7547*Ln(DBH) - 3.7217 R^2 = 0.6105
Acacia nilotica and Acacia senegal	5-57	2.8-25.5	135	H = 0.0023*(DBH)^2 + 0.209 *(DBH) + 3.6328 R^2 = 0.6795
Avicennia marina	1-38	0.9-5.1	1028	H = -0.0026x2 + 0.194x + 1.1227 R^2 = 0.5246
Dalbergia sissoo	5-50	2.7-30.8	70	H = 0.0038*(DBH)^2 + 0.2994*(DBH) + 3.5519 R^2 = 0.6875
Eucalyptus camaldulensis	5-82	2.9-48.8	279	H= -0.0051*(DBH)^2 + 0.7603*(DBH) - 0.6817 R^2 = 0.9262
Olea ferruginea	5-64	2.9-11.9	307	H = -0.001*(DBH)^2 + 0.2077*(DBH) + 2.9166 R^2 = 0.5139
Populous euphretica				Height=3.5097*LnD-1.4113 (Ali, 2017)
Prosopis cineraria	6-46	3-16.7	46	H= -0.0043*(DBH)^2 + 0.4443*(DBH) + 1.5809 R^2 = 0.7317
Prosopis juliflora	5-48	3.9-12.5	83	H = -0.0066x2 + 0.4956x + 1.9189 R^2 = 0.7947
Quercus incana	5-45	2-27	241	H = 0.0099*(DBH)^2 - 0.1211 *(DBH) + 4.8764 R^2 = 0.5789
Tamarix aphyla	5-50	2.9-17.2	83	H = -0.0002*(DBH)^2 + 0.3243*(DBH) + 2.6741 R^2 = 0.6423
Tamarix dioca				Height=0.189+ 2.3523*Ln(D) Dry Biomass =0.477*(D^2*H)^0.5755 Adopted from Ali 2019
Salvadora oleoides	5-85	2.9-6.9	36	H = -0.0011*(DBH)^2 + 0.1437*(DBH) + 2.6217 R^2 = 0.7538
Zizyphus mauritiana				Height= 1.844+1.8072*Ln(DBH) Adopted from Ali, 2019

Species	Range of DBH (cm)	Range of height (m)	Number of sample trees	Model with R^2 value
Other broadleaved species Sindh and Balochistan (Other than the above spp.)	5-42	2.1-6.8	48	H = -0.0048*(DBH)^2 + 0.2699*(DBH) + 1.6994 R^2 = 0.5797

Table 7: Finally selected Diameter-Height Models with descriptive statistics

Tree Species	Model	n Tree H	RMSE	RMSE (%)
Acacia modesta	3.7547*LN('tree'[dbh1]) - 3.7217	178	2.056678	0.94073
Acacia nilotica	0.0023*'tree'[dbh1]^2 + 0.209 *'tree'[dbh1] + 3.6328	162	3.084328	0.796641
Acacia senegal	1.3+8.244514*exp(-7.752015*'tree'[dbh1]^-1)	5	1.804457	0.747458
Avicennia marina	0.3+0.8245704*('tree'[dbase]^0.4524907)	1182	0.689303	0.804327
Azadirachta indica	1.3+8.244514*exp(-7.752015*'tree'[dbh1]^-1)	1	0.4999	
Bombax cieba	ABS(10.467*LN('tree'[dbh1])-18.124)	20	4.54334	0.611551
Ceriops tagal	0.3+divide('tree'[dbase](0.7097502+ 0.4683141*'tree'[dbase]))	7	0.385601	0.772674
Cordia myxa	1.3+8.244514*exp(-7.752015*'tree'[dbh1]^-1)	1	3.37207	
Dalbergia sissoo	'-0.0038*'tree'[dbh1]^2 + 0.2994*'tree'[dbh1] + 3.5519	84	5.640391	1.004632
Eucalyptus camaldulensis	'-0.0051*'tree'[dbh1]^2 + 0.7603*'tree'[dbh1] - 0.6817	299	3.773671	0.549415
Melia azedarach	'-0.0018*'tree'[dbh1]^2+0.3569*'tree'[dbh1]+2.4247	28	1.61835	1.156527
Olea europaea	1.3+8.244514*exp(-7.752015*'tree'[dbh1]^-1)	5	1.534307	2.035815
Olea ferruginea	'-0.001*'tree'[dbh1]^2 + 0.2077*'tree'[dbh1] + 2.9166	504	1.970239	0.897573
Phoenix dactylifera	1.3+1.7688957*'tree'[dbh1]^0.5153645	6	3.446182	2.360731
Phoenix dactylifera	1.3+8.244514*exp(-7.752015*'tree'[dbh1]^-1)	6	3.446182	2.360731
Populus euphratica	1.3+8.244514*exp(-7.752015*'tree'[dbh1]^-1)	4	5.097504	1.166179
Prosopis cineraria	'-0.0043*'tree'[dbh1]^2 + 0.4443*'tree'[dbh1] + 1.5809	130	2.518336	1.001638
Prosopis juliflora	'-0.0066*'tree'[dbh1]^2 + 0.4956*'tree'[dbh1] + 1.9189	164	1.174541	0.637536
Rhizophora mucronata	0.3+divide('tree'[dbase](0.7097502+ 0.4683141*'tree'[dbase]))	24	0.463549	0.964783
Salvadora oleoides	'-0.0011*'tree'[dbh1]^2+0.1437*'tree'[dbh1]+2.6217	41	0.904609	0.728306
Tamarix aphylla	'-0.0002*'tree'[dbh1]^2+0.3243*'tree'[dbh1]+2.6741	89	2.178909	0.67044
Tamarix dioca	1.3+8.244514*exp(-7.752015*'tree'[dbh1]^-1)	11	2.229631	1.400198
Zizyphus mauritiana	1.3+1.7688957*'tree'[dbh1]^0.5153645	12	2.709529	2.788045
Zizyphus mauritiana	1.3+8.244514*exp(-7.752015*'tree'[dbh1]^-1)	12	2.709529	2.788045

3.4.5. Allometric models for Above-Ground Tree Biomass estimation

Aboveground biomass models are available for 63% of all observed tree species. For the remaining species the allometric equation developed by Chave et.al. 2014 was used. For mangrove species of Avicennia marina, Ceriops tagal, and Rhizophora mucronate the models reported by Dharmawan and Siregar, 2008, Komiyama et al., 2005, and Amira, 2008 were used. Table 8 presents the allometric models applied for Above Ground Biomass estimation in Sindh.

Table 8: Allometric models applied for Above Ground Biomass estimation

Sr. No	*Species Type*	Allometric Equation	Reference/ Province
1	*Acacia modesta*	M= 0.2267(D^2H)^0.8226	Ali 2019 (Sindh & Punjab)
2	*Accacia nilotica Acacia senegal*	M= 0.0569(D^2*H)^0.9745	Ali 2019 (Sindh & Punjab)
3	*Avicennia marina*	M = 0.1848 * D2.3524 WD=0.65	Dharmawan and Siregar, 2008 (cited by MoC, 2020)
4	*Ceriops tagal*	M = 0.251 * Wood Density * D^2.46	Komiyama et al., 2005 (cited by MoCC, 2018)
5	*Eucalyptus camaldulensis*	M= 0.023(D^2*H)^0.9985	Ali 2020 (KP)
6	*Olea ferruginea*	M= 7.8863+0.0556(D^2H)	Ali 2019 (Sindh & Punjab)
7	*Olea ferruginea*	M= 7.8863+0.0556(D^2H)	Ali 2020 (KP)
8	*Other Mix*	M=0.0673*(WD*DBH^2*H) ^0.976	Chave et al, 2014, RFEL/NFMS, 2020
9	*Other species*	M=Exp (-2.187+0.916*ln (WD*D^2*H))	RFEL/NFMS, 2020
10	*Populus euphratica*	M=0.112*(0.4D^2H)^0.916	Ali 2019 (Sindh & Punjab
11	*Rhizophora mucronate*	BIOMASS = 0.043 * D^2.63 WD= 0.74	Amira, 2008 (cited by MoC, 2018
12	*Tamarix dioca*	M=0.477*(D^2*H)^0.5755	Ali 2019 (Sindh & Punjab)
13	*Zizyphus mauritiana*	M= EXP((-9.46108+0.52923*Ln(Height)+2.15113*Ln(DBH)))*0.8*1.4*1000	Ali 2019 (Sindh & Punjab)

3.5. Emission Factors for Forest Degradation

Emission factors for forest degradation were developed by determining the carbon density values (C t/ha) of different forest strata and the difference between these values when one forest stratum is degraded into a lower stratum due to logging or other anthropogenic activities. The following strata were used:

- open forest (canopy cover 11-30%)
- sparse forest (canopy cover 31-50%)
- medium (canopy cover 51-70%)
- dense (canopy cover >70%)

3.6. Reference Period

The reference period for the current MRV is 2016-2020. Activity data for deforestation and forest degradation was generated for 2012-2016 and 2016-2020. Data for development of Emission Factors was collected during 2021-2022.

3.7. Emissions Calculation

The sample plot-based MRV process involves a modelling chain with the following critical steps:

- Field measurements of carbon pools and data entries;
- Height modelling for individual trees;
- Allometric biomass modelling of aboveground biomass for individual trees;
- Applying default root-shoot ratios to estimate belowground biomass;
- Laboratory analysis to determine moisture content in shrubs and litter;
- Laboratory Analysis to determine carbon contents in soil samples;
- Aggregation of plot level data;
- Expansion of plot level data to derive values on per ha basis;
- Conversion of carbon density values to CO_2 equivalent

3.8. Emission Calculation from Deforestation

Deforestation refers to the conversion of forest land into another land use category. The emission factors for deforestation represent emissions per hectare of land which has been converted to non-forest land use. Activity data i.e., estimate of area on deforestation is provided by SLMS. Activity data (AD) when multiplied by Emission Factor (EF) gives emissions as given below:

$$Emissions = EF * AD$$

Table 9 indicates the formulas that have been used to derive the emission factors by forest strata. As shown in Table 10 respective default values of carbon densities for land use classes of cropland and grassland were adopted (IPCC, 2006). For wetland, settlement and other land no specific default values were available and were assumed as zero (IPCC, 2006).

Table 9: Formulas used to derive the emission factors for deforestation

	Term	**Variable Definition/Formula**
Forest converted to non-forest land (cropland, grassland, settlements, wetlands and other land)	A	Forest carbon density, mean AGC+BGC+Deadwood+litter (ton C/ha)
	B	Non-forest land mean carbon density (ton C/ha) (IPCC, default values)
	EF	(A-B) x 3.67
	EF	**Emission factor (ton CO2-e/ha)**

Table 10: Default values of carbon densities in non-forest land use classes adopted for EFs/RFs of deforestation/ Enhancement

Forest type/ climate zone	Default C densities (C t/ ha)		
	Cropland	Grassland	Wetland/ Settlement/ Otherland
Subtropical broad leaved (Scrub)	1.8	4.1	0
Tropical Thorn Forests	1.8	4.1	0
Riverine Forests	1.8	4.1	0
Mangrove Forests	1.8	4.1	0
Irrigated Plantation	1.8	4.1	0

Source: IPCC, 2006

3.9. Emission Calculation from Forest Degradation

Emissions of forest degradation were determined by multiplying Emissions factors for degradation with activity data. Activity data for forest degradation was provided by SLMS and emissions factors were developed by calculating the difference of carbon density values for different canopy cover strata within the same forest type. The following table indicates the formulas that have been used to derive the emission factor for forest degradation.

Table 11: Formulas used to derive the emission factor for forest degradation

	Term	Variable Definition/Formula
Dense Moist Temperate Forest converted to Sparse Moist Temperate Forest	A	Forest carbon density in Dense Moist Temperate Forest, mean AGC+BGC + Deadwood + litter (ton C/ha)
	B	Forest carbon density in Sparse Moist Temperate, mean AGC+BGC+ Deadwood + litter (ton C/ha)
	EF	(A-B) x 3.67
	EF	**Emission factor (ton CO2-e/ha)**

3.10. Removal/Sequestration from Enhancement

improved resulting in enhancement of carbon stock. Removal Factors are the opposite of Emission Factors of deforestation or forest degradation.

Removal from enhancement were determined by multiplying removal factors for afforestation or reforestation with activity data. Activity data for enhancement was provided by SLMS and removal factors were developed by calculating the difference of carbon density values for different strata and canopy cover classes.

The following table indicates the formulas that have been used to derive the removal factors (RF) for enhancement when i) non-forest land is converted to forest ii) forest degradation is reversed i.e., sparse forest is converted to dense forest. The RFs for enhancement are calculated for the normal age of each forest type. Mean ages of different forest types taken from Ali, 2018; Ali, 2019 and Ali, 2020 are given as Annex-16.

Table 12: Formulas used to derive the removal factors (RF) for enhancement

Enhancement	Term	Variable Definition/Formula
Other land converted to forest	**A**	Forest carbon density, mean AGC + BGC + Deadwood + litter (ton C/ha)
	B	Non-forest land mean carbon density (ton C/ha) (IPCC, default values)
	RF*	(A-B) x 3.67
	RF*	**Removal Factor (ton CO_2-e/ha)**
Sparse Moist Temperate Forest converted to Dense Moist Temperate Forest	A	Forest carbon density in Dense Moist Temperate Forest, mean AGC+BGC + Deadwood + litter (ton C/ha)
	B	Forest carbon density in Sparse Moist Temperate, mean AGC + BGC + Deadwood + litter (ton C/ha)
	RF	(A-B) x 3.67
	RF	**Removal Factor (ton CO_2-eq/ha)**

*Note: RF for enhancement covers the normal age of each forest type. Annual removals in each forest type can be derived by dividing the removals by the mean age of each forest type. Mean ages of each forest type are given as Annex-16.

4. RESULTS

4.1. Forest Type Wise Carbon Stock

The total carbon stock in Sindh's forests was estimated as 42.45 million tons for 2020. The average carbon density in the forests was estimated as 143.2 t/ha. The highest carbon density was found in mangrove forests (239 t/ha), irrigated plantations (69 t/ha), subtropical broad-leaved forests (57 t/ha), riverine forest (42 t/ha) and dry tropical thorn forest (35 t/ha). Total carbon stocks and carbon densities in different forest types are shown in Table 13.

Table 13: Carbon stocks in different forest types

Forest Type	2016	2020		
	Area (ha)	Area (ha)	C Density (tC/ha)	Carbon Stock Mt C)
Subtropical broad leaved (Scrub)	1,990	1,488	57.01	0.08
Tropical Thorn Forests	29,829	42,167	35.24	1.49
Riverine Forests	85,890	82,862	42.20	3.50
Mangrove Forests	127,585	151,045	238.85	36.08
Irrigated Plantation	14,746	18,838	69.05	1.30
Total	**260,039**	**296,400**		**42.45**

Note: The carbon densities are based on the available sample data collected during the current forest inventory; however, the values can vary with age, soil conditions and other variables.

4.2. Emission Factors for Deforestation

Emission factors for different forest types of Punjab (including ICT) are given in Table 14. Emission factors for deforestation in each forest type was derived by subtracting the mean carbon density of the respective non-forest land use from the mean carbon density of forest land use and multiplying the value with 3.67 (Table 9). Default values of mean carbon densities of the five non-forest land use classes were taken from IPCC, 2006 guidelines. The emission factors for deforestation exclude soil organic carbon due to the reason that changes in SOC occur over a period of more than 20 years. Since emissions factors for different forest types at sub-national scale have high standard errors due to insufficient numbers of sample plots at the subnational level, the national level emission factors developed under this assignment were used. Uncertainties of emission factors for deforestation are given as Annex-13.

Table 14: Emission Factors for Deforestation (excluding soil organic carbon)

Forest type	Mean Carbon Density (tC/ha)	SE (%)	Emission Factor (EF) (CO2e t/ha)				
			Forest-Cropland	Forest-Grassland	Forest-wetland	Forest-Settlement	Forest-Other land
Subtropical broad leaved (Scrub)	10.1	15.3	30.3	21.9	36.9	36.9	36.9
Tropical Thorn Forests	7.5	25.7	20.7	12.3	27.3	27.3	27.3
Riverine Forests	5.6	27.3	13.9	5.4	20.5	20.5	20.5
Mangrove Forests	15.2	14.3	49.2	40.8	55.8	55.8	55.8
Irrigated Plantation	22.5	19.8	76.0	67.5	82.6	82.6	82.6

4.3. Estimates of Deforestation

The total area of deforestation in Sindh was determined as 26,976 ha during the reference period of 2016-2020 with an average annual deforestation rate of 6,744 ha. The highest deforestation was found in riverine forest (24,036 ha) followed by tropical thorn forest (1,324 ha). Deforestation estimates of different forest types are given in Table 15. Forest types map, LULC maps and LULC Change maps are given in Annex-3, 4, 5 and 6.

Table 15: Estimates of deforestation in different forest types

Forest type	Forest-Cropland	Forest-Grassland	Forest-wetland	Forest-Settlement	Forest-Other land	Grand Total	%
Subtropical broad leaved (Scrub)	84	111	26	0	722	943	3.50
Tropical Thorn Forests	962	124	198	0	40	1,324	4.91
Riverine Forests	15,102	4,184	3,131	5	1,616	24,036	89.10
Mangrove Forests	11	26	96	1	538	672	2.49
Grand Total	**16,158**	**4,445**	**3,451**	**6**	**2,916**	**26,976**	**100.00**

4.4. Estimates of Forest Degradation

The total area under forest degradation in Sindh was estimated as 15,712 ha for the period from 2016 to 2020. The highest degradation was found in riverine forest (53%), followed by mangrove forest (25%) and tropical thorn forest (22%). Estimates of forest degradation in different forest types are given in Table 16.

Table 16: Estimates of Forest Degradation

Forest Type	Total degradation (ha)	%
Subtropical broad leaved (Scrub)	8	0.05
Tropical Thorn Forests	3,495	22.25

Riverine Forests	8,315	52.92
Mangrove Forests	3,893	24.78
Total	**15,712**	**100.00**

4.5. Estimates of Enhancement

The total area of forest enhancement due to reforestation and afforestation in Sindh during 2016-2020 was estimated as 72,521 ha. The average annual enhancement rate was found as 18,130 ha for the period. The highest enhancement was found in mangrove forest (30,107 ha) followed by riverine forest (27,053 ha) and Tropical Thorn Forests (14,750 ha). Enhancement estimates of different forest types are given in Table 17.

Table 17: Estimates of Enhancements

Forest type	Cropland-Forest	Grassland-Forest	Wetland-Forest	Settlement-Forest	Otherland-Forest	Grand Total	%
Subtropical broad leaved (Scrub)	8	504	41	0	57	611	0.84
Tropical Thorn Forests	4,047	7,171	1,578	1	1,952	14,750	20.34
Riverine Forests	7,316	10,867	3,015	2	5,853	27,053	37.30
Mangrove Forests	5	1	4,018	9	26,074	30,107	41.52
Grand Total	**11,376**	**18,544**	**8,652**	**13**	**33,936**	**72,521**	**100.00**

4.6. Emissions from Deforestation

The total emissions from deforestation were estimated as 0.427 million tons of CO_2e between 2016 and 2020. The largest share of CO_2 emissions came from riverine forest (77%), followed by mangrove forest (9%), subtropical broadleaved scrub forest (8%) and tropical thorn forest (7%), as shown in the Table 18 and Figure 6.

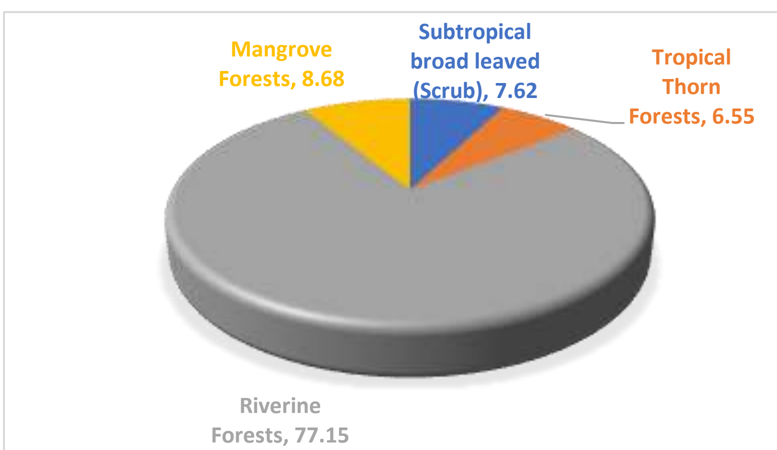

Figure 6: Distribution of Emissions from Deforestation

Table 18: Emissions from Deforestation

Forest type	Forest-Cropland			Forest-Grassland			Forest-wetland			Forest-Settlement			Forest-Other land			Total Defor. (ha)	Total Emiss. (Mt CO2e)
	Defor. (ha)	EF (CO2e t/ha)	Emiss. (Mt CO2e)	Defor. (ha)	EF (CO2e t/ha)	Emiss. (Mt CO2e)	Defor. (ha)	EF (CO2e t/ha)	Emiss. (Mt CO2e)	Defor. (ha)	EF (CO2e t/ha)	Emiss. (Mt CO2e)	Defor. (ha)	EF (CO2e t/ha)	Emiss. (Mt CO2e)		
Subtropical broad leaved (Scrub)	84	30	0.003	111	22	0.002	26	37	0.001	0	37	0.000	722	37	0.027	943	0.033
Tropical Thorn Forests	962	21	0.020	124	12	0.002	198	27	0.005	0	27	0.000	40	27	0.001	1324	0.028
Riverine Forests	15102	14	0.209	4184	5	0.023	3131	20	0.064	5	20	0.000	1616	20	0.033	24036	0.329
Mangrove Forests	11	49	0.001	26	41	0.001	96	56	0.005	1	56	0.000	538	56	0.030	672	0.037
Total	**16158**		**0.232**	**4445**		**0.028**	**3451**		**0.076**	**6**		**0.000**	**2916**		**0.091**	**26976**	**0.427**

4.7. Emission Factors for Forest Degradation

Emission factors for forest degradation were developed on the basis of changes in the canopy cover class within a forest type based on the national definition of forest degradation. Emission factors for forest degradation are given in Table 19.

Table 19: Emission factors for forest degradation

Forest Type	Dense - Medium		Dense - Sparse		Dense - Open		Medium - Sparse		Medium - Open		Sparse - Open	
	Δ C (t/ha)	ΔCO2e (t/ha)	ΔC (t/ha)	Δ CO2e (t/ha)	Δ C (t/ha)	ΔCO2e (t/ha)	Δ C (t/ha)	ΔCO2e (t/ha)	ΔC (t/ha)	ΔCO2e (t/ha)	ΔC (t/ha)	ΔCO2e (t/ha)
Subtropical broad leaved (Scrub)	4.5	16.4	21.2	77.7	27.5	100.9	16.7	61.3	23.1	84.5	6.3	23.3
Tropical Thorn	-	-	-	-	-	-	14.9	54.5	25.4	93.0	10.5	38.4
Riverine	-	-	-	-	-	-	9.7	35.4	11.8	43.2	2.1	7.7
Mangroves	6.1	22.5	2.4	8.7	9.6	35.1	-3.7	-13.7	3.4	12.6	7.2	26.4
Irrigated Plantation	2.7	9.9	-1.9	-6.9	14.4	52.7	4.6	16.8	17.1	62.6	12.5	45.7

4.8. Emissions and Removals from Forest Degradation and Improvement in Forest Cover Density

Total emissions from forest degradation were estimated as 0.27 million tons CO_2e during 2016-2020 and the total enhancement from improvement in canopy cover was estimated as 0.57 million tons CO_2e during this period. Thus, the net balance is removal of 0.30 million tons of CO_2e. The details of forest type wise degradation and enhancement are given in Table 20 and Annex-11 and 12.

Table 20: Emissions and Removals from Forest Degradation and Improvement in Forest Cover Density

Forest Type	Total degradation (ha)	Emissions (Mt CO2e)	Total Improvement in forest cover density (ha)	Removals (Mt CO2e)	Net Emissions (Mt CO2e)
Subtropical broad leaved (Scrub)	8	0.00	317	0.01	-0.01
Tropical Thorn*	3,495	0.10	5,185	0.11	-0.01
Riverine*	8,315	0.10	8,663	0.06	0.04
Mangroves	3,893	0.06	33,134	0.39	-0.33
Total	**15,712**	**0.27**	**47,298**	**0.57**	**-0.30**

* No Emission Factor (EF) available for canopy cover > 70 %

4.9. Removals from Enhancement

Under the present study removals were estimated both for the normal age of forests and the reporting period of four years (2016-2020). The total removal from enhancement due to reforestation and afforestation was estimated as 2.3 million tons of CO_2e between for the normal age of forests. For the four-year period (2016 to 2020) the total removals from enhancement were assessed as 1.1667 million tons of CO2e, with 83% removals originating from Mangroves Forests, and 15 % from Riverine Forests (Table 21).

4.10. Overall situation of emissions and removals

Keeping in view the overall situation of emissions and removals from deforestation, forest degradation and enhancement due to afforestation, reforestation and improvement in forest cover, a net balance of 1.04 million tons of CO_2e were sequestered during 2016 to 2020 in Sindh. The overall picture of emissions and removals from deforestation, forest degradation and enhancement is given in the Table 22.

Table 21: Removals from enhancement

Forest type	Cropland-Forest			Grassland-Forest			Wetland-Forest			Settlement-Forest			Otherland-Forest			Total Enha (ha)	Total Rem (Mt CO2e) (For the normal age of forest)	Total Rem (Mt CO2e) (for 4 years, 2016-2020)	%
	Enha (ha)	RF (CO2e t/ha)	Rem (Mt CO2e)	Enha (ha)	RF (CO2e t/ha)	Rem (Mt CO2e)	Enha (ha)	RF (CO2e t/ha)	Rem (Mt CO2e)	Enha (ha)	RF (CO2e t/ha)	Rem (Mt CO2e)	Enha (ha)	RF (CO2e t/ha)	Rem (Mt CO2e)				
Subtropical broad leaved (Scrub) Forest	9	30.3	0.0003	504	21.9	0.011	41	36.9	0.002	0	36.9	0.000	57	36.9	0.0021	611	0.0149	0.0035	0.30
Tropical Thorn Forests	4047	20.7	0.0839	7171	12.3	0.088	1578	27.3	0.043	1	27.3	0.000	1952	27.3	0.0533	14750	0.2685	0.0316	2.71
Riverine Forests	7316	13.9	0.1015	10867	5.4	0.059	3015	20.5	0.062	2	20.5	0.000	5853	20.5	0.1198	27053	0.3421	0.1711	14.66
Mangrove Forests	5	49.2	0.0002	1	40.8	0.000	4018	55.8	0.224	9	55.8	0.001	26074	55.8	1.4559	30107	1.6810	0.9606	82.33
Total	**11376**		**0.1858**	**18544**		**0.158**	**8652**		**0.331**	**13**		**0.001**	**33936**		**1.6311**	**72521**	**2.3065**	**1.1667**	**100.00**

Note: EF/ RFs were developed for the normal age of the forests. Removals for the reporting period of four years were derived as (Removals for 4 years=Removals for normal age/ mean age of forest x 4). Mean ages of different forest types were taken from Ali, 2018; Ali, 2019 and Ali, 2020 (Annex-16).

Table 22: Overall carbon emissions and removals

Forest Type	Emissions from deforestation (Mt CO2e)	Emissions from forest degradation (Mt CO2e)	Removals from enhancement during 4 years (2016-20) (Mt CO2e)	Removals from improvement in degradation (Mt CO2e)	Net balance (Mt CO2e)
Subtropical broad leaved (Scrub)	0.033	0.000	0.004	0.010	0.019
Tropical Thorn Forests	0.028	0.103	0.032	0.108	-0.009
Riverine Forests	0.329	0.103	0.171	0.059	0.203
Mangrove Forests	0.037	0.064	0.961	0.393	-1.252
Total	**0.427**	**0.270**	**1.167**	**0.570**	**-1.040**

5. RECOMMENDATIONS FOR IMPROVEMENT

5.1. Improvement of Activity Data

Instead of using post-monsoon, cloud-free, least haze a single image, in the era of data-cube, intense temporal coverage of Landsat 8 and 9, it is recommended to use an annual composite for the image classification. The yearly composite will better understand phonological stages to distinguish vegetation classes (Cropland, Shrubland, etc.) from the forest.

Instead of relying only on the spectral response of the images, it is recommended to integrate spectral indices of vegetation, water, snow, soil, etc. along with the spectral reflectance.

In terms of forest degradation, the combination of SMA and time series could improve the results

There is strong need for improvement of the forest ecological and forest types boundaries and maps. The forest ecological zones and forest types mapping prepared during the NFMS development phase, while used during the current assignment resulted in miss classification of forest types. Though the WWF-Pakistan GIS and Forestry experts tried to correct these mistakes and adjust the maps using local knowledge about the area and VHR Google maps, however further improvement is needed to avoid any miss classification.

Though, ground data from the forest inventory were used along with high resolution imageries and local knowledge (through meetings with local experts and their feedback) for validating LULC mapping and change detection, however separate and elaborate ground truthing needs to be conducted by the GIS/ RS team for generating more reliable LULC statistics and activity data regarding deforestation, enhancement and forest degradation.

5.2. Improvement of Emission Factors

The emission factors of deforestation and forest degradation are based on national average values of carbon stocks in different forest types. Thus, these are good for estimating emissions at national level. Emission factors at subnational level could not be developed due to the reason that the number of sample plots used for data collection were statistically not sound at subnational level and the resultant standard errors were quite large. The limited number of sample plots at Sub-National level were due to limited time for the assignment. However, it is recommended to develop emission factors at subnational level by taking statistically sufficient number of sample plots at the subnational level.

Forest degradation was included in the current GHG-Inventory report to develop emission factors for degradation using canopy cover as the proxy variable for estimating forest degradation. However, this method is not perfect as sometimes canopy cover does not exhibit the real picture of degradation or enhancement of carbon stocks in forest. The methodology needs further improvement and adoption of other proxy indicators. Permanent sample plots should be established for continuous monitoring of the forest carbon stocks and assessment of forest growth and biomass as well as forest degradation.

The current GHG-Inventory was confined to forest land use class while for the five non-forest land use classes IPCCs recommended default values of carbon densities were adopted. There is a dire need to develop emission factors for other land uses to get reliable estimates of emissions and removal for land use and landcover changes.

Locally developed allometric models can yield Tier 3 level estimates of carbon stocks and emissions. There is already a representative selection of allometric biomass models existing for the temperate forests, subtropical and riverine forests but it is recommended to develop biomass models for tree species found in other forest types and strata particularly for mangrove species.

Manual recording of field survey data on paper data-sheets need to be replaced by Mobile Data Entry Aps (FAO Opensource Aps) to save time and reduce errors in data entry and recording as well as increase transparency and ensure quality. This will need proper training of the forest inventory teams.

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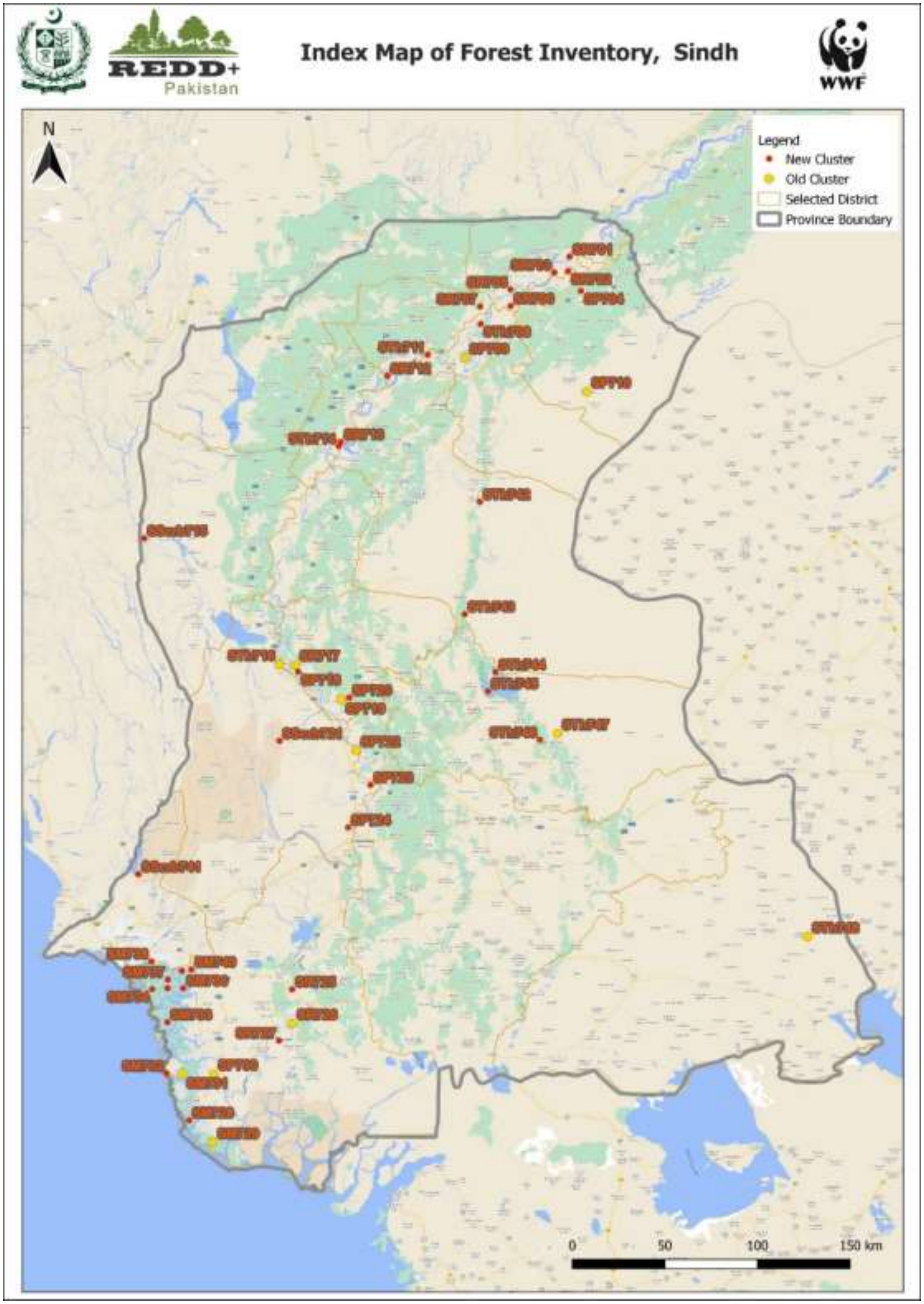
7. ANNEXES

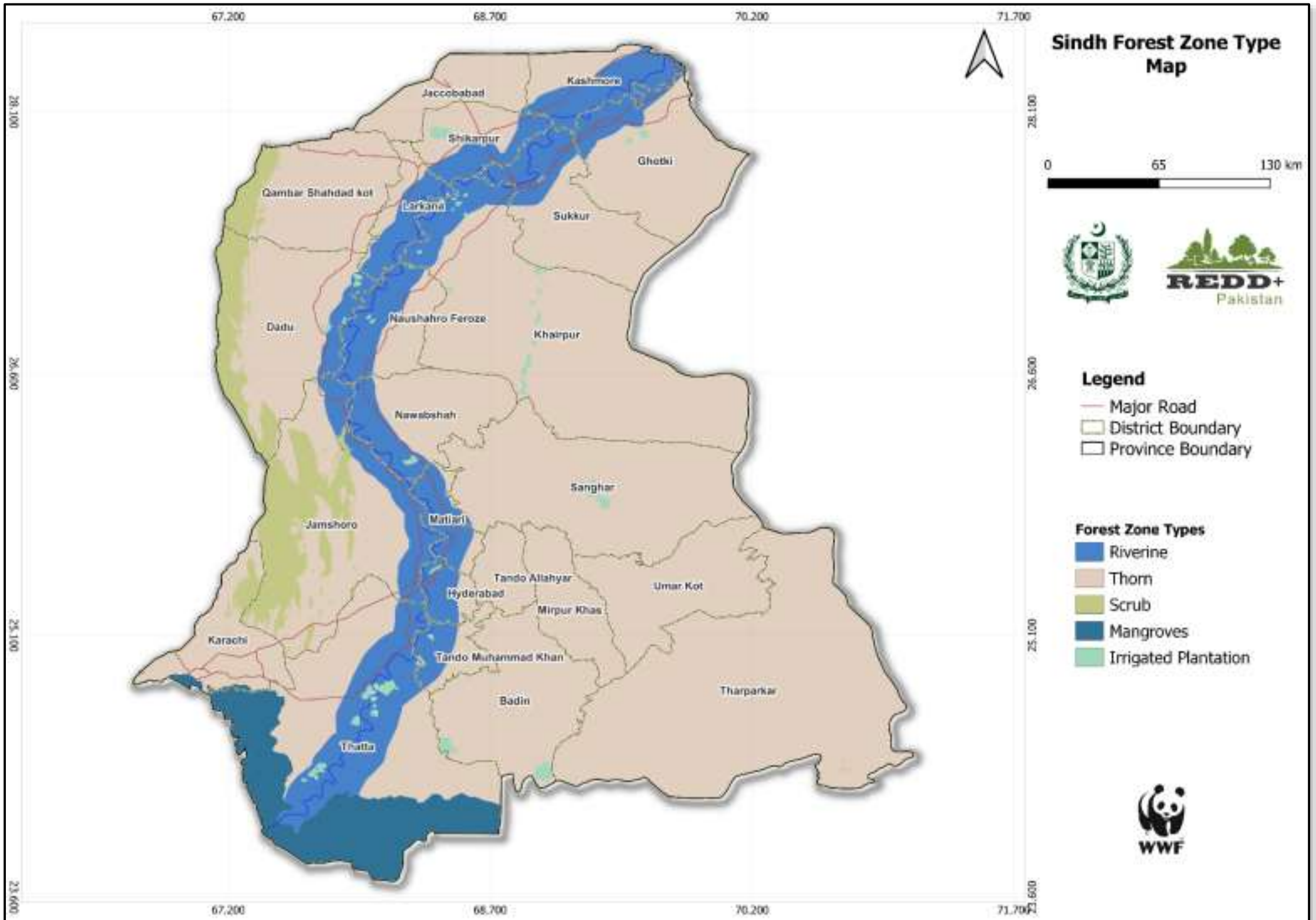
Annex 1. Forest Inventory Plots Location Map (Sindh)



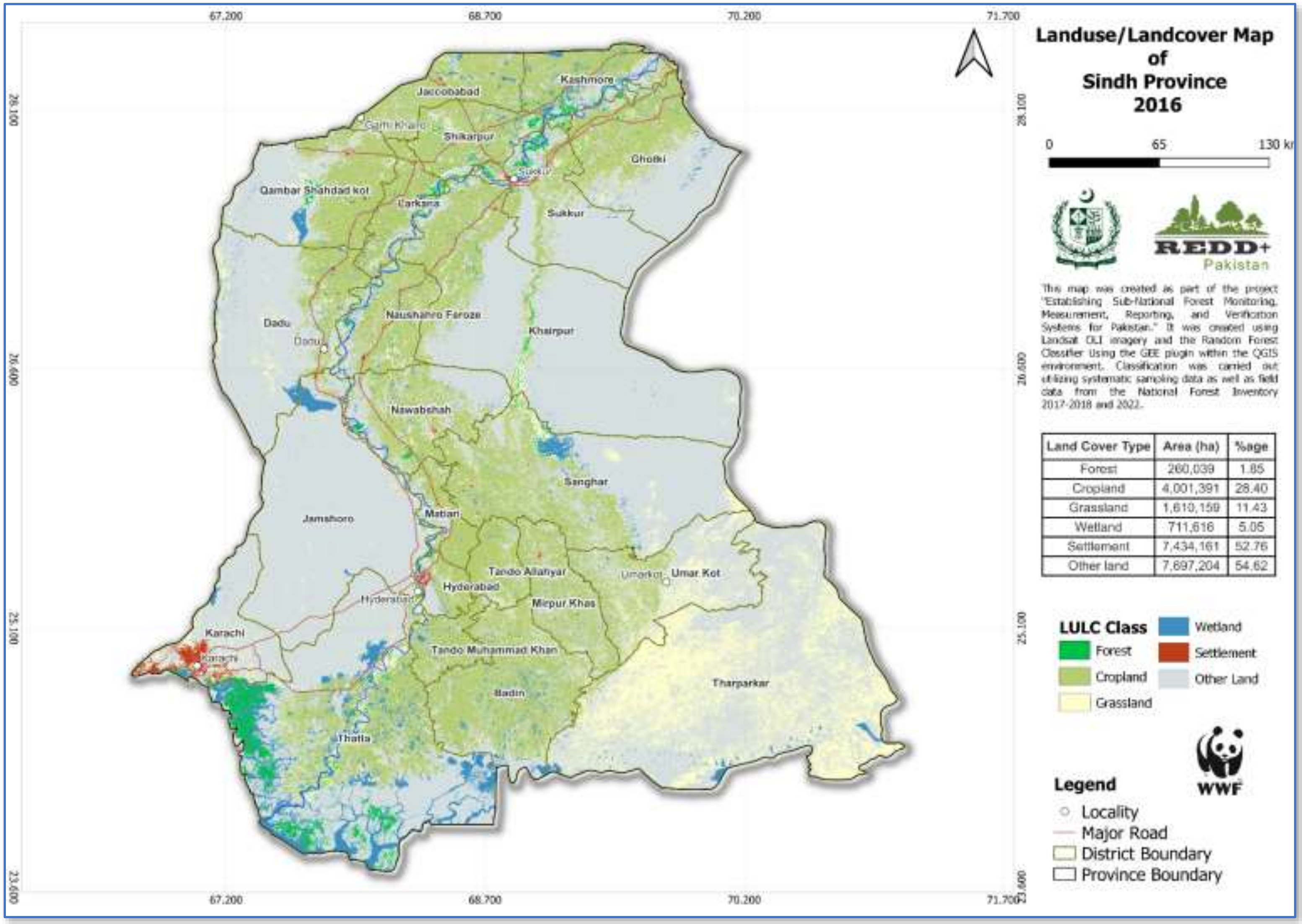
Annex-2: Coordinates of accessible forest inventory sample plots (clusters) in Sindh

Cluster no.	Map coordinates SRS	Map coordinates (X)	Map coordinates (Y)	GPS Coordinates SRS	GPS Coordinates (X)	GPS Coordinates (Y)	GPS Accuracy	GPS Avg. Z	Slope	aspect
711	EPSG:32642	470080.5	3072720	EPSG:32642	470079	3072719	3	68	1.104	SE
709	EPSG:32642	490088	3071030	EPSG:32642	490088	3071030	3	62	1.57	SE
702	EPSG:32642	545717.9	3117817	EPSG:32642	545716	3117818	4	69	1.57	SE
704	EPSG:32642	552688.5	3107127	EPSG:32642	552689	3107127	3	49	2.24	S
717	EPSG:32642	398423	2905281	EPSG:32642	398423	2905281	3	41	1.9	SE
710	EPSG:32642	555867	3052690	EPSG:32642	555870	3052691	3	56	2.3	SE
712	EPSG:32642	448285.8	3061283	EPSG:32642	448284	3061283	4	54	0.8	NW
706	EPSG:32642	514802.8	3099068	EPSG:32642	514806	3099061	3	59	2.6	E
714	EPSG:32642	421992.5	3023306	EPSG:32642	421991	3023318	3	39	1.5	SW
713	EPSG:32642	423071.1	3025644	EPSG:32642	423072	3025649	3	43	0.73	NW
741	EPSG:32642	313888.5	2792168	EPSG:32642	313889	2792168	3	107	2.17	NE
726	EPSG:32642	396949	2711479	EPSG:32642	396950	2711477	3	20	1.1	SW
744	EPSG:32642	506557.1	2901329	EPSG:32642	506556	2901328	3	35	0.7	NW
715	EPSG:32642	317010.7	2973560	EPSG:32642	317012	2973564	4	1270	20.9	NW
748	EPSG:32642	674969	2758350	EPSG:32642	674968	2758349	3	139	11	NW
730	EPSG:32642	354445.5	2684168	EPSG:32642	354446	2684169	3	2	1.8	NE
727	EPSG:32642	389774.7	2702255	EPSG:32642	389776	2702255	3	3	0.9	N
722	EPSG:32642	431467	2858922	EPSG:32642	431467	2858922	3	32	1.12	N
724	EPSG:32642	427069.6	2817430	EPSG:32642	427073	2817431	3	25	0.367	NE
725	EPSG:32642	396890.3	2729947	EPSG:32642	396891	2729946	4	12	2	NE
716	EPSG:32642	390099	2905356	EPSG:32642	390098	2905360	3	22	1.2	W
723	EPSG:32642	439182.7	2840349	EPSG:32642	439182	2840347	5	25	0.36	NE
747	EPSG:32642	539999	2868032	EPSG:32642	539998	2868031	3	9	0.76	NW
745	EPSG:32642	502532.5	2891027	EPSG:32642	502531	2891026	3	24	1.68	NE
720	EPSG:32642	427742.5	2887500	EPSG:32642	427741	2887498	3	23	2.17	NW
719	EPSG:32642	423279	2886652	EPSG:32642	423281	2886652	4	29	0.4756	W
721	EPSG:32642	390060.4	2864156	EPSG:32642	390060	2864159	3	177	2.43	
708	EPSG:32642	498540.5	3089325	EPSG:32642	498540	3089327	3	65	4.27107	NW
737	EPSG:32642	329816.2	2735215	EPSG:32642	329817	2735214	3	5		
731	EPSG:32642	337525	2684353	EPSG:32642	337525	2684354	3	-20	0.874	SE
733	EPSG:32642	329515.8	2712240	EPSG:32642	329515	2712241	3	0	2.294	
746	EPSG:32642	530498.4	2864718	EPSG:32642	530497	2864717	3	14	1.218	NE
718	EPSG:32642	400104.8	2901388	EPSG:32642	400107	2901378	3	28	5.67	W
732	EPSG:32642	329181.3	2684586	EPSG:32642	329181	2684585	3	-2	1.103	
740	EPSG:32642	342537.3	2740671	EPSG:32642	342537.3	2740671	3	-1	0.874	
729	EPSG:32642	354067	2647256	EPSG:32642	354067	2647256	3	11	0.3677	
734	EPSG:32642	321332.5	2730080	EPSG:32642	321332.5	2730080	3	51		
735	EPSG:32642	329625.4	2730599	EPSG:32642	329625.4	2730599	4	11	0.766	
736	EPSG:32642	338058.5	2730498	EPSG:32642	338058.5	2730498	3	32		
738	EPSG:32642	320882.6	2745062	EPSG:32642	320882.6	2745062	5			
728	EPSG:32642	341328.8	2659188	EPSG:32642	341328.8	2659188	3	0		

Annex-3: Forest types map of Sindh

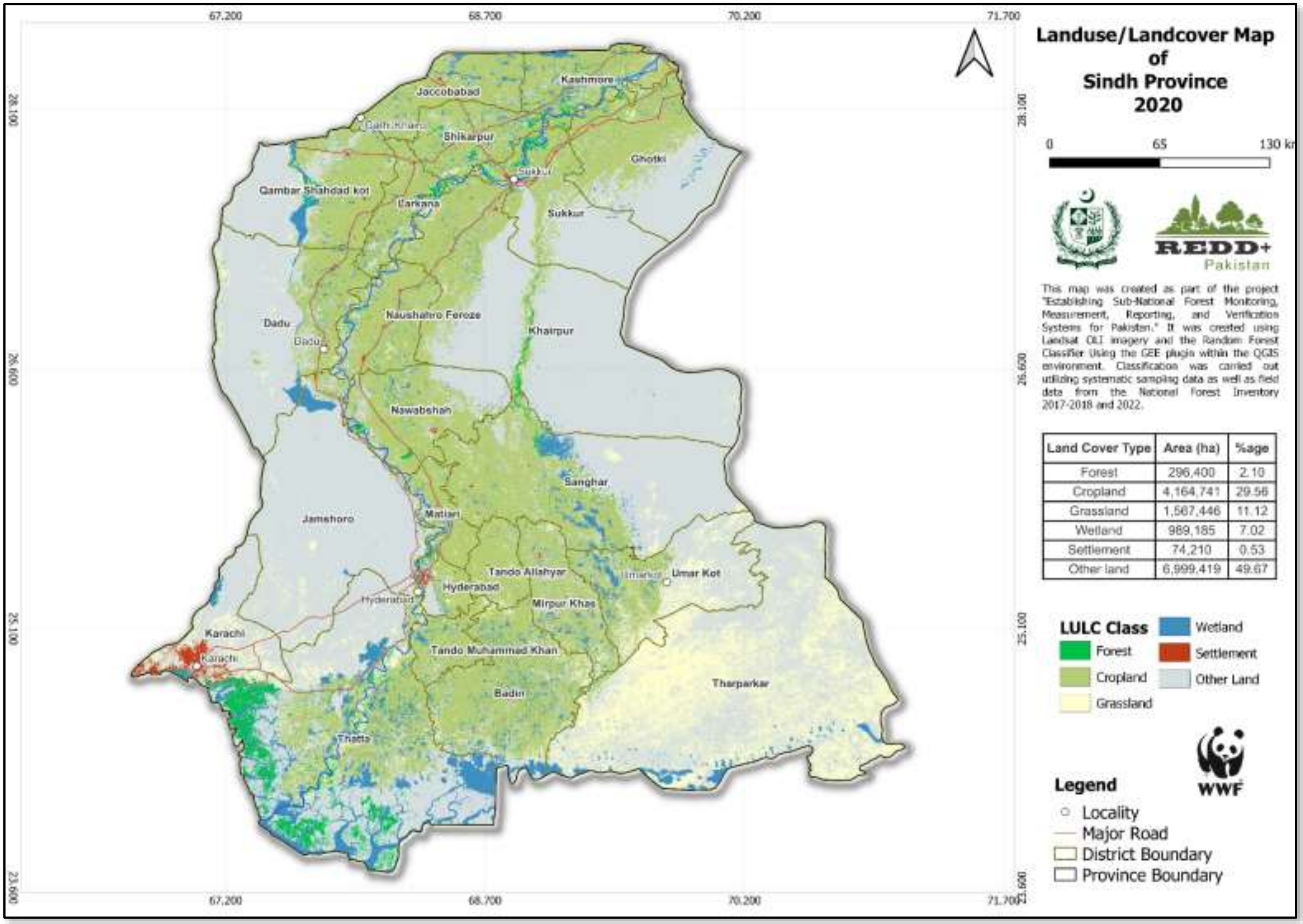


Annex-4: LULC Maps 2016-Sindh

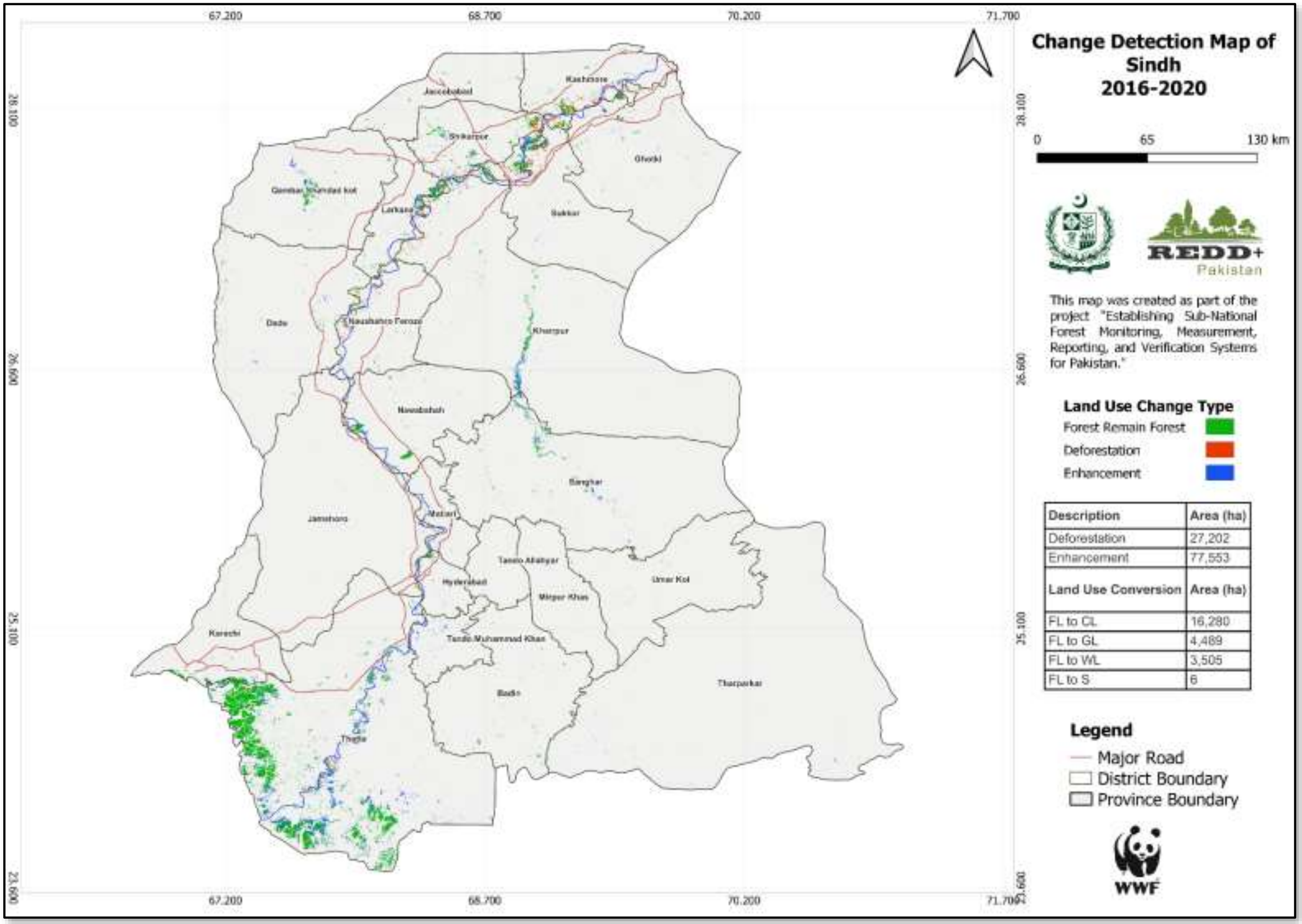


Land Cover Type	Area (ha)	%age
Forest	260,039	1.85
Cropland	4,001,391	28.40
Grassland	1,610,159	11.43
Wetland	711,616	5.05
Settlement	7,434,161	52.76
Other land	7,697,204	54.62

Annex-5: LULC Maps 2020-Sindh



Annex-6: Land Use Land Cover Change Map of Sindh



Annex-7. Wood Densities by Species (adopted from National FREL/ FRL Report 2020)

Species		Wood Density (ton/m3)	Species	Wood Density (ton/m3)
Abies pindrow		0.420	Juniperus excelsa	0.504
Acacia catechu		0.801	Leucaena leucocephala	0.450
Acacia modesta		0.835	Mallotus philippinensis	0.676
Acacia nilotica		0.689	Malus domestica	0.610
Aesculus indica		0.465	Melia azedarach	0.451
Ailanthus altissima		0.536	Millingtonia hortensis	0.640
Albizia lebbeck		0.596	Monotheca buxifolia	0.851
Albizia procera		0.587	Morus alba	0.578
Alnus nitida		0.370	Olea ferruginea	0.887
Armenian plum		0.675	Picea smithiana	0.430
Avicennia marina		0.650	Pinus gerardiana	0.500
Azadirachta indica		0.620	Pinus roxburghii	0.327
Betula utilis		0.500	Pinus wallichiana	0.430
Bombax cieba		0.350	Pongamia pinnata	0.640
Capparis decidua		0.691	Populus caspica	0.370
Cedrela serrata		0.390	Populus deltoides	0.417
Cedrus deodara		0.430	Prosopis cineraria	0.663
Celtis australis		0.550	Prosopis juliflora	0.800
Celtis eriocarpa		0.549	Prunus bokharensis	0.548
Ceriops tagal		0.758	Prunus spp.	0.606
Cordia myxa		0.330	Punica granatum	0.771
Dalbergia sissoo		0.760	Pyrus pashia	0.643
Diospyros lotus		0.706	Quercus incana	0.635
Dodonaea viscosa		0.840	Rhizophora mucronata	0.820
Ehretia acuminata		0.526	Robinia robesta	0.610
Ehretia spp.		0.526	Salix acmophylla	0.424
Eucalyptus camaldulensis		0.570	Salix tetrasperma	0.340
Eucalyptus citriodora		0.830	Salvadora oleoides	0.594
Ficus religiosa		0.443	Schinus molle	0.525
Ficus sp.		0.443	Syzygium cumini	0.760
Gmelina arborea		0.560	Tamarix aphylla	0.640
Grewia optiva		0.646	Tecomella undulata	0.500
Juglans regia		0.533	Ulmus wallichiana	0.440
			Zizyphus mauritiana	0.583

Annex-8: Revised Forest measurement manual (provided as separate file)

Annex-9: Data Storage and Processing report (provided as separate file)

Annex-10: Forest type and pool wise breakup of carbon densities (with and without SOC)

Forest Type	AGC (t/ha)	BGC (t/ha)	DWC (t/ha)	Litter (t/ha)	Total (t/ha) without SOC	SOC	Total (t/ha) with SOC
Subtropical broad leaved (Scrub)	8.0	2.0	0.0	0.0	**10.1**	46.9	**57.0**
Tropical Thorn	5.9	1.5	0.0	0.0	**7.5**	27.8	**35.2**
Riverine	4.5	1.1	0.0	0.0	**5.6**	36.6	**42.2**
Mangroves	12.2	3.0	-	0.0	**15.2**	223.6	**238.9**
Irrigated Plantation	18.0	4.5	0.1	0.0	**22.5**	46.5	**69.0**

Note: The carbon densities are based on the available sample data collected during the current forest inventory, however the values can vary with age, soil conditions and other variables.

Annex-11: Details of emissions from forest degradations

Forest Type	Dense - Medium			Dense - Sparse			Dense - Open			Medium - Sparse			Medium - Open			Sparse - Open			Total	
	EF/RF CO2e (t/ha)	Deg. (ha)	Emis (Mt CO2e)	EF/RF CO2e (t/ha)	Deg. (ha)	Emis (Mt CO2e)	EF/RF CO2e (t/ha)	Deg. (ha)	Emis (Mt CO2e)	EF/RF CO2e (t/ha)	Deg. (ha)	Emis (Mt CO2e)	EF/RF CO2e (t/ha)	Deg. (ha)	Emis (Mt CO2e)	EF/RF CO2e (t/ha)	Deg. (ha)	Emis (Mt CO2e)	Deg. (ha)	Emis (Mt CO2e)
Subtropical broad leaved (Scrub)	16.4	4	0.0001	77.7	0	0.0000	100.9	0	0.0000	61.3	3	0.0002	84.5	0	0.0000	23.3	1	0.0000	8	0.0003
Tropical Thorn*	-	994	-	-	444	-	-	288	-	54.5	966	0.0527	93.0	353	0.0328	38.4	450	0.0173	3,495	0.1028
Riverine*	-	3,193	-	-	1,161	-	-	477	-	35.4	1,923	0.0681	43.2	640	0.0276	7.7	922	0.0071	8,315	0.1029
Mangroves	22.5	1,251	0.0281	8.7	95	0.0008	35.1	47	0.0017	-13.7	776	-0.0107	12.6	97	0.0012	26.4	1,627	0.0429	3,893	0.0640
Total		**5,443**	**0.0282**		**1,700**	**0.0008**		**813**	**0.0017**		**3,668**	**0.1104**		**1,089**	**0.0616**		**3,000**	**0.0673**	**15,712**	**0.2700**

* No Emission Factor (EF) available for canopy cover > 70 %

Annex-12: Details of removals from improvement in forest cover density

Forest Type	Medium-Dense			Sparse-Dense			Open-Dense			Sparse-Medium			Open-Medium			Open-Sparse			Total	
	EF/RF CO2e (t/ha)	Enh. (ha)	Rem (Mt CO2e)	EF/RF CO2e (t/ha)	Enh. (ha)	Rem (Mt CO2e)	EF/RF CO2e (t/ha)	Enh. (ha)	Rem (Mt CO2e)	EF/RF CO2e (t/ha)	Enh. (ha)	Rem (Mt CO2e)	EF/RF CO2e (t/ha)	Enh. (ha)	Rem (Mt CO2e)	EF/RF CO2e (t/ha)	Enh. (ha)	Rem (Mt CO2e)	Enh. (ha)	Rem CO2e (t/ha)
Subtropical broad leaved (Scrub)	16.4	210	0.003	77.7	19	0.001	100.9	0	0.000	61.3	83	0.005	84.5	1	0.000	23.3	5	0.000	317	0.010
Tropical Thorn*	-	2,257	-	-	848	-	-	226	-	54.5	1,196	0.065	93.0	322	0.030	38.4	335	0.013	5,185	0.108
Riverine*	-	5,761	-	-	869	-	-	115	-	35.4	1,351	0.048	43.2	181	0.008	7.7	386	0.003	8,663	0.059
Mangroves	22.5	15,369	0.345	8.7	1,300	0.011	35.1	150	0.005	-13.7	9,620	-0.132	12.6	954	0.012	26.4	5,741	0.151	33,134	0.393
Total		**23,597**	**0.349**		**3,036**	**0.013**		**491**	**0.005**		**12,250**	**-0.014**		**1,457**	**0.050**		**6,467**	**0.167**	**47,298**	**0.570**

* No Emission Factor (EF) available for canopy cover > 70 %

Annex-13: Uncertainties of Emission Factors of deforestation

Forest Type	Forest C Density t/ha	SE%	EF (t/ha)	SE EF (t/ha)	Sampling Error (t/ha)	95% CI	
EF deforestation (Forest to cropland)							
Subtropical broad leaved (Scrub)	10.06	15.26	30.28	4.62	9.06	21.22	39.34
Tropical Thorn Forests	7.45	25.74	20.72	5.33	10.46	10.27	31.18
Riverine Forests	5.58	27.25	13.87	3.78	7.41	6.46	21.28
Mangrove Forests	15.23	14.30	49.24	7.04	13.80	35.44	63.03
EF deforestation (Forest to grassland)							
Subtropical broad leaved (Scrub)	10.06	15.26	21.85	3.33	6.54	15.31	28.39
Tropical Thorn Forests	7.45	25.74	12.29	3.16	6.20	6.09	18.49
Riverine Forests	5.58	27.25	5.44	1.48	2.90	2.53	8.34
Mangrove Forests	15.23	14.30	40.80	5.83	11.44	29.37	52.24
EF deforestation overall (Forest to wetlands/ settlement/ other land)							
Subtropical broad leaved (Scrub)	10.06	15.26	209.03	31.90	62.53	146.50	271.57
Tropical Thorn Forests	7.45	25.74	129.21	33.26	65.19	64.01	194.40
Riverine Forests	5.58	27.25	154.75	42.17	82.66	72.09	237.41
Mangrove Forests	15.23	14.30	875.79	125.23	245.45	630.35	1121.24

Annex-14: Uncertainties of Emission Factors of Forest Degradation

Annex-14: (Part-a)

Forest Type	Dense - Medium							Dense - Sparse						
	ΔC (t/ha)	ΔCO2e (t/ha)	SE%	SE ΔCO2e (t/ha	Samp. Error (t/ha)	95% CI		ΔC (t/ha)	ΔCO2e (t/ha)	SE%	SE ΔCO2e (t/ha	Samp. Error (t/ha)	95% CI	
Subtropical broad leaved (Scrub)	4.46	16.37	36.44	5.96	11.69	24.75	48.12	21.18	77.65	37.75	29.31	57.45	-19.70	95.19
Tropical Thorn	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Riverine	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mangroves	6.13	22.46	13.51	3.03	5.95	7.56	19.45	2.38	8.71	58.40	5.09	9.97	48.42	68.37
Irrigated Plantation	2.71	9.92	99.07	9.83	19.26	79.81	118.34	-1.89	-6.92	98.23	-6.80	-13.33	111.56	84.90

Annex-14: (Part-b)

Forest Type	Dense-Open							Medium-Sparse						
Subtropical broad leaved (Scrub)	27.52	100.91	34.60	100.91	34.60	0.00	69.21	16.71	61.28	21.77	13.34	26.15	-4.38	47.92
Tropical Thorn	-	-	-	-	-	-	-	14.88	54.55	89.40	48.77	95.58	-6.18	184.98
Riverine	-	-	-	-	-	-	-	9.67	35.45	49.04	17.38	34.07	14.97	83.12
Mangroves	9.57	35.09	58.63	35.09	58.63	0.00	117.25	-3.75	-13.75	58.89	-8.10	-15.87	74.75	43.02
Irrigated Plantation	14.36	52.66	108.54	52.66	108.54	0.00	217.08	4.59	16.84	24.26	4.09	8.01	16.25	32.26

Annex-14: (Part-c)

Forest Type	Medium-Open							Open-Sparse						
	ΔC (t/ha)	ΔCO2e (t/ha)	SE%	SE ΔCO2e (t/ha)	Samp. Error (t/ha)	95% CI		ΔC (t/ha)	ΔCO2e (t/ha)	SE%	SE ΔCO2e (t/ha)	Samp. Error (t/ha)	95% CI	
Subtropical broad leaved (Scrub)	23.06	84.54	15.70	13.28	26.02	-10.32	41.72	6.34	23.26	18.54	4.31	8.45	10.09	26.99
Tropical Thorn	25.35	92.96	118.79	110.43	216.45	-97.66	335.25	10.48	38.41	80.66	30.98	60.73	19.93	141.38
Riverine	11.77	43.16	32.79	14.15	27.74	5.05	60.52	2.11	7.72	51.90	4.01	7.85	44.05	59.75
Mangroves	3.44	12.63	59.11	7.47	14.63	44.48	73.75	7.19	26.38	81.99	21.63	42.39	39.60	124.38
Irrigated Plantation	17.07	62.58	52.15	32.64	63.97	-11.82	116.13	12.47	45.73	50.54	23.11	45.30	5.24	95.84

Annex-15: Province wise uncertainties of Activity Data (Forest Loss)

Province	Forest loss area	Standard error	Variance (SE^2)	95 % CI	Uncertainty of AD Deforestation (2016-2020)
Azad Jammu and Kashmir	612	297	88209	582	95%
Balochistan	1046	619	383161	1,214	116%
Gilgit Baltistan	485	47	2209	92	19%
Khyber Pakhtunkhwa	7838	5926	35117476	11,615	148%
Punjab	7379	4607	21224449	9,030	122%
Sindh	27202	2386	5692996	4,677	17%
Islamabad Capital Territory	448	238	56644	467	104%
TOTAL	**45010**			**27,677**	

Annex-16: Mean Ages of Different Forest Types

Forest Type	Mean DBH_cm	Mean Age
Subtropical BL Scrub	17	17
Irrigated Plantation	20	10
Mangrove	7	8
Riverine	14	7
Dry Tropical Thorn	17	34

Source: Ali, 2018; Ali, 2019 and Ali, 2020