GREEN HOUSE GAS INVETORY OF FORESTRY SECTOR-PUNJAB PROVINCE

Ministry of Climate Change

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REPORT PREPARED BY WWF-PAKISTAN

ISLAMABAD

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ACRONYMS

AD	Activity data
AGB	Above Ground Biomass
AJK	Azad Jammu & Kashmir (autonomous territory)
AKRS	Aga Khan Rural Support Program
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
Emiss.	Emission
EF	Emission Factor
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)
KIU	Karakorum International University
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
PFRI	Punjab Forestry Research Institute
PSA	Punjab Forest Services Academy
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
Rem/ Remov	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
UoBS	University of Baltistan
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 present sub-national GHG-Inventory report covers both Punjab and Islamabad Capital Territory (ICT); 205,344 km^2 area of Punjab province and 905 km^2 area of the ICT.

For the current Sub-National GHG-Inventory methodologies developed during the 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 Punjab the total calculated sample plots were 370 (74 clusters) out which 352 plots (72 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.

The total forest carbon stock (including soil organic carbon) in Punjab was estimated as 40.97 million tons and for ICT as 1.48 million tons for the year 2020 with an average carbon density of 62.8 t/ha (Punjab) and 57.2 t/ ha (ICT).

The total area of deforestation (excluding Irrigated Plantations) in Punjab during 2016-2020 was determined as 6,655 ha while in ICT the deforestation was estimated 448 ha. The average annual deforestation rate was calculated as 1,664 ha in Punjab and 112 ha in ICT for the reference period of 2016-2020. In Punjab the highest deforestation was found in sub-tropical broadleaved scrub forest (2438 ha),

followed by Tropical Thorn Forests (2139 ha). In ICT the only forest type is the subtropical broad-leaved (scrub) forest and all of the deforestation occurred here.

During the reference period of 2016-2020 the total area under forest degradation in Punjab was estimated as 74,441 ha with the highest degradation in subtropical broad-leaved scrub forest (59%) followed by subtropical Chir pine forest and (29%). In ICT the degradation of was assessed as 2,815 ha in the sub-tropical broad leaved (Scrub) forests.

Enhancement during 2016-2020 (due to reforestation and afforestation) in Punjab and ICT were assessed as 3752 ha and 388 ha respectively. The average annual enhancement rate in Punjab was calculated as 938 ha while in ICT was 97 ha during 2016-2020. In Punjab the highest enhancement was found in tropical thorn forest (68%) followed by riverine forest (23%).

The total emissions from deforestation in Punjab and ICT were estimated as 0.163 and 0.015 million tons of CO2e respectively between 2016 and 2020. In Punjab the largest share of CO2 emissions originated from tropical Subtropical broad leaved (Scrub) forest (46%), followed by subtropical thorn forest (26%).

Total emissions from forest degradation in Punjab were estimated as 2.49 million tons CO2e during 2016-2020 and the total enhancement from improvement in canopy cover was estimated as 0.97 million tons CO2e during this period. Thus, the net balance is emissions of 1.51 million tons of CO2e. In ICT the total emissions from forest degradation were estimated as 0.065 million tons CO2e during 2016-2020 while total enhancement was estimated as 0.071 million tons CO2e with a net balance of removals as 0.005 million tons CO2e.

The total removal from enhancement due to reforestation and afforestation was estimated as 0.013 million tons of CO2e in Punjab and 0.003 million tons of CO2e in ICT between 2016 and 2020. The largest share of CO_2 removal was found in Riverine Forest (50%), followed by Sub-Tropical Thorn Forest (33%) and subtropical Broad Leaved (Scrub) forests (11%).

Overall, a total of 1.66 and 0.007 million tons of CO_2e have been emitted from deforestation, and forest degradation during 2016 to 2020 in Punjab and ICT respectively.

1. INTRODUCTION

1.1. Brief introduction of Punjab province

Punjab province is located between latitude 31.1704° N, longitude 72.7097°. Punjab is the second largest province in Pakistan and has a total area of 205,344 sq km. According to the 2017 census its total population is 110 million ("Quick Stats | Punjab Portal" 2022). Punjab has relatively mild winters and hot summers with annual average temperature varying from less than 7-12 ^oC in the cool zone to above 25^o C. In winter the temperature goes down to -2^{o}C while in summers to goes even higher than 40^{o}C (Siddiqui and Javid 2018). Average annual rainfall varies from 960 mm in sub-mountain northern parts to 460 mm in central and southern plains (Siddiqui and Javid 2018). Major forest types are; 1) Moist temperate; 2). Sub-tropical Chir Pine; 2) Sub-tropical broadleaved Scrub 3). Riverine and 4). Irrigated plantations.

1.2. Objectives of the Green House Gas Inventory

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 carbon stock assessment

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

1.3.1. Adjustment and adoption of the national standards

1.3.1.1. Definition of Forest

The national definition of forest (2017) was adopted for this assignment. It defines 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".

1.3.1.2. Deforestation

As recommended by the National FREL/ FRL Submission (2020) the FAO (2015) definition of the deforestation was adopted for the current Sub-national Forest Carbon Stocks Assessment. 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).

1.3.1.3. 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".

1.3.1.4. Methodology for assessment of Forest Degradation

Methodology for assessment of the forest degradation has been developed and agreed during the development of the Sub-NFMS and Sub-National GHG-Inventory (2021-22) 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.

1.3.1.5. 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).

1.3.1.6. Emission Factors

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

1.3.1.7. 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		

1.3.2. 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 Punjab the total calculated sample plots were 370 (74 clusters) out which 352 plots (72 clusters) were 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 present Sub-national GHG-Inventory of forestry sector of Punjab covers the total area of Punjab province (205,344 km^2) and the total area of the Islamabad Capital Territory (ICT) (905 km^2). However, the forest area, carbon estimates and emissions are given separately in this report.

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 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. 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 (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 conducting the Forest GHG-Inventories.

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 and Removal Factors for Deforestation and Enhancement

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**

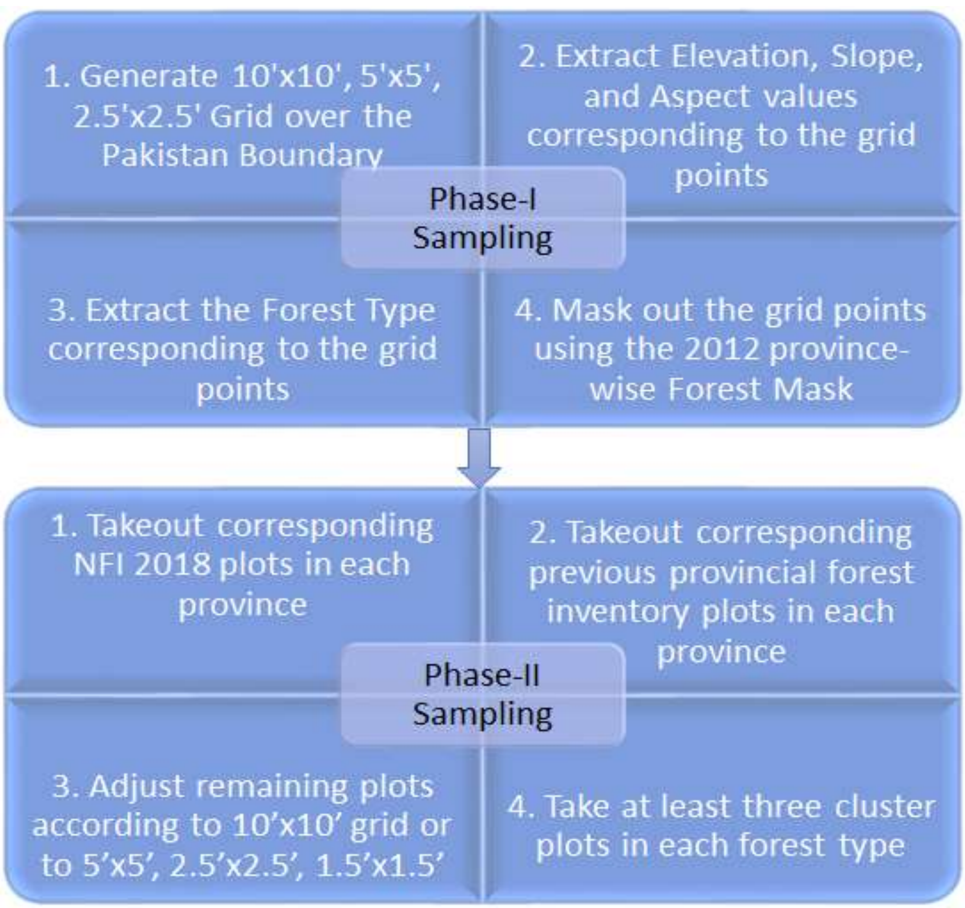

Figure 1: Stratified two-phase sampling process with integration of the SLMS process

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 3). 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 3). Complete workflow of the forest inventory is given in Figure 2.

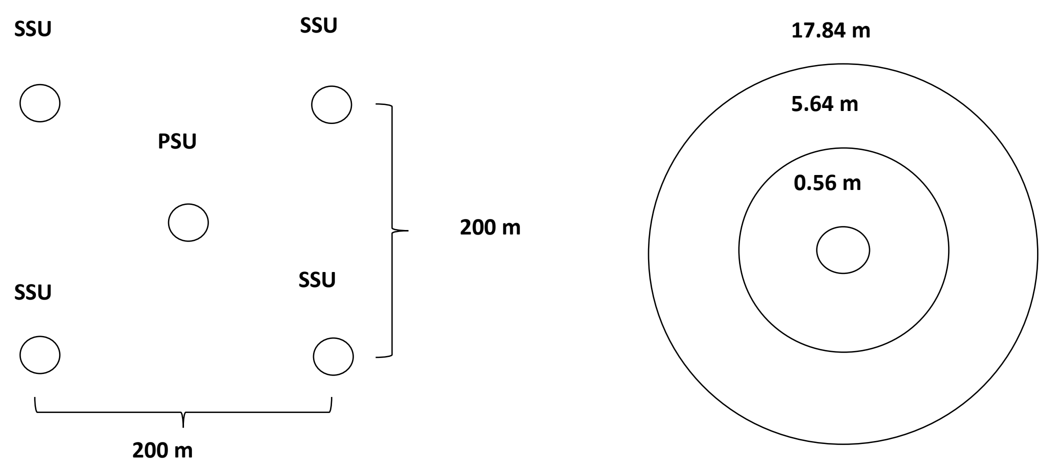

Figure 2: Forest Inventory Workflow (Source: adopted from NFMS-MRV Report, MoCC, 2020)

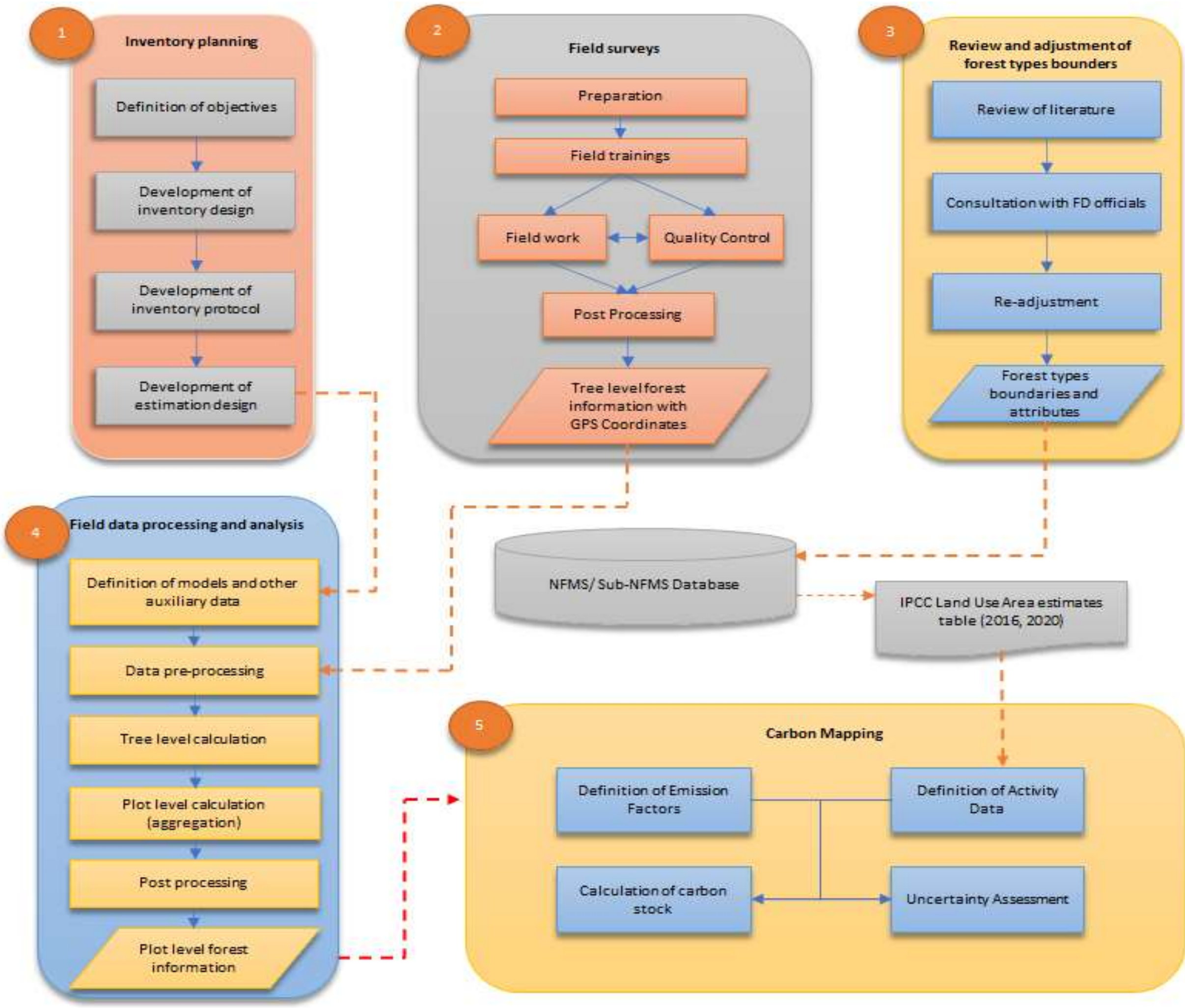

Figure 3: Clustered primary and secondary sample units (plots). Source: NFMS – MRV Report, 2020

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-7 (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
  - 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.
  - 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.
    - 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.
- 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.
    - 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.
- 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.
- 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:

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

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-8 (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 4. 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".

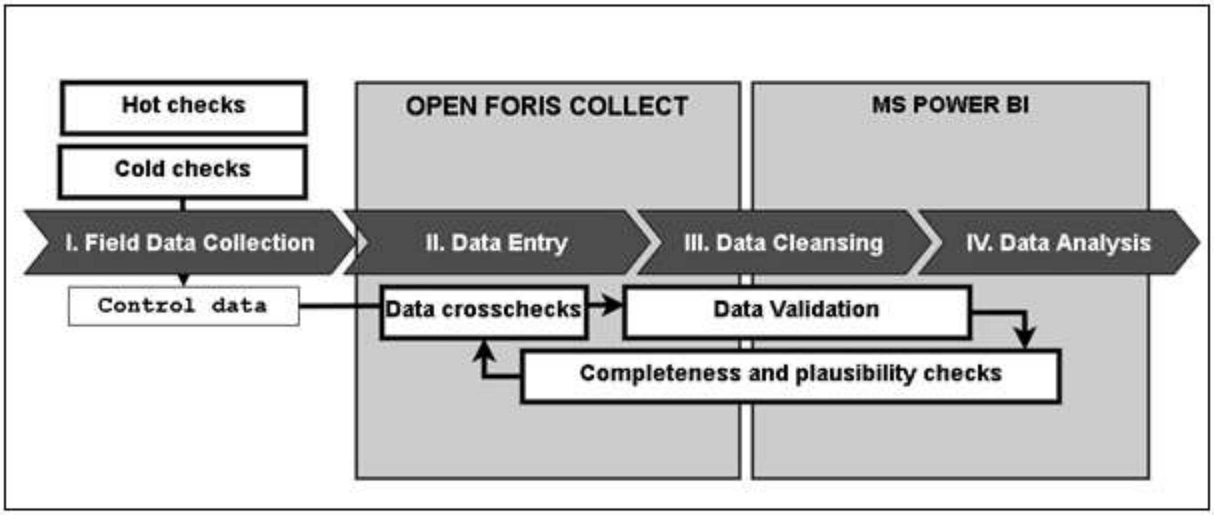

Figure 4:Data storage and processing workflow

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).

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
Abies pindrow	5-120	3.9-49.5	135	H = 2.5597*(DBH)^0.5929 R^2 = 0.7636
Acacia modesta	5-46	2-11.6	131	H = 3.7547*Ln(DBH) - 3.7217 R^2 = 0.6105
Acacia nilotica and Acacia senegal Acacia catechu	5-57	2.8-25.5	135	H = 0.0023*(DBH)^2 + 0.209 *(DBH) + 3.6328 R^2 = 0.6795
Aesculus indica	9-116.33	4.4-47.2	44	H= 0.0016*(DBH)^2 + 0.2037*(DBH) + 3.2397 R^2 = 0.9094
Cedrus deodara	5-94.5	2-39.4	210	H= 1.1322(DBH)^0.7551 R^2 = 0.7937
Dalbergia sissoo	5-50	2.7-30.8	70	H = 0.0038*(DBH)^2 + 0.2994*(DBH) + 3.5519 R^2 = 0.6875

Species	Range of DBH (cm)	Range of height (m)	Number of sample trees	Model with R^2 value
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
Pinus roxburghii	5-106.5	2-39.6	548	H = -0.0006*(DBH)^2 + 0.3518 *(DBH) + 5.2698 R^2 = 0.7225
Picea smithiana	5-108.2	2-41.2	149	H = -0.0035x2 + 0.6912x + 0.2213 R^2 = 0.7367
Pinus wallichiana	4-134	1.5-44.5	611	H = -0.0015*(DBH)^2 + 0.504*(DBH) + 2.3565 R^2 = 0.8037
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
Other broadleaved species Punjab (Other than the above spp.)	5-55	3.1-31.4	225	H = -0.001*(DBH)^2 + 0.4047*(DBH) + 2.3505 R^2 = 0.6253

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

Tree Species	Model	n Tree H	RMSE	RMSE (%)
Abies pindrow	2.5597*'tree'[dbh1]^0.5929)	143	6.04237	0.641715
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
Aesculus indica	0.0016*'tree'[dbh1]^2 + 0.2037*'tree'[dbh1] + 3.2397	47	2.657656	0.304918
Ailanthus altissima	'-0.0018*'tree'[dbh1]^2+0.3569*'tree'[dbh1]+2.4247	15	2.748417	0.824467
Bombax cieba	ABS(10.467*LN('tree'[dbh1])-18.124)	20	4.54334	0.611551
Capparis aphylla	'-0.0018*'tree'[dbh1]^2+0.3569*'tree'[dbh1]+2.4247	6	1.956157	3.766952
Cedrus deodara	1.1322*'tree'[dbh1]^0.7551)	299	4.395158	0.595499
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
Diospyros lotus	'-0.0018*'tree'[dbh1]^2+0.3569*'tree'[dbh1]+2.4247	12	1.254836	1.137489
Eucalyptus camaldulensis	'-0.0051*'tree'[dbh1]^2 + 0.7603*'tree'[dbh1] - 0.6817	299	3.773671	0.549415
Ficus carica	'-0.0018*'tree'[dbh1]^2+0.3569*'tree'[dbh1]+2.4247	16	1.932007	0.948785
Juglans regia	'-0.0018*'tree'[dbh1]^2+0.3569*'tree'[dbh1]+2.4247	24	2.512621	0.636264
Mallotus phillipennesis	2.6226*'tree'[dbh1]^0.4075	52	1.414962	0.683102
Malus domestica	'-0.0018*'tree'[dbh1]^2+0.3569*'tree'[dbh1]+2.4247	4	1.558773	1.459925
Melia azedarach	'-0.0018*'tree'[dbh1]^2+0.3569*'tree'[dbh1]+2.4247	28	1.61835	1.156527
Morus alba	'-0.0018*'tree'[dbh1]^2+0.3569*'tree'[dbh1]+2.4247	24	3.803151	0.8319
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
Phyllanthus emblica	1.3+1.7688957*'tree'[dbh1]^0.5153645	16	2.931546	0.687758
Picea smithiana	1.3+31.70924806*(1-exp((-0.03712483*'tree'[dbh1])))^1.46781861	189	5.211965	0.543062
Pinus roxburghii	'-0.0006*'tree'[dbh1]^2 + 0.3518 *'tree'[dbh1] + 5.2698	554	4.164238	0.632527
Pinus wallichiana	'-0.0015*'tree'[dbh1]^2 + 0.504*'tree'[dbh1] + 2.3565)	923	4.543665	0.55644
Platanus orientalis	1.3+1.7688957*'tree'[dbh1]^0.5153645	1	0.283511	
Populus ciliata	'-6.9198+8.4004*LN('tree'[dbh1])	14	7.801454	2.454332
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
Prunus domestica	'-0.0018*'tree'[dbh1]^2+0.3569*'tree'[dbh1]+2.4247	6	2.41334	0.887002
Prunus dulcis	1.3+8.244514*exp(-7.752015*'tree'[dbh1]^-1)	10	1.282075	1.356375
Prunus persica	'-0.0018*'tree'[dbh1]^2+0.3569*'tree'[dbh1]+2.4247	1	2.5002	
Pyrus pashia	'-0.0018*'tree'[dbh1]^2+0.3569*'tree'[dbh1]+2.4247	12	3.335052	1.356741
Quercus incana	0.0099*'tree'[dbh1]^2-0.1211*'tree'[dbh1]+4.8764	350	5.151243	1.598699
Robinia pseudoacacia	'-0.0018*'tree'[dbh1]^2+0.3569*'tree'[dbh1]+2.4247	1	1.8358	
Salix tetrasperma	1.3+8.244514*exp(-7.752015*'tree'[dbh1]^-1)	25	3.532232	0.932172
Salvadora oleoides	'-0.0011*'tree'[dbh1]^2+0.1437*'tree'[dbh1]+2.6217	41	0.904609	0.728306
Syzygium cumini	'-0.0018*'tree'[dbh1]^2+0.3569*'tree'[dbh1]+2.4247	4	1.062898	0.524342
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

Unknown	'-0.0018*'tree'[dbh1]^2+0.3569*'tree'[dbh1]+2.4247	3	0.746974	0.398705
Zizyphus mauritiana	1.3+1.7688957*'tree'[dbh1]^0.5153645	12	2.709529	2.788045

3.4.5. Allometric models for Above-Ground Tree Biomass estimation

Above-ground biomass models are available for 63% of all observed tree species. For coniferous species, which did not have any national level models, the generic coniferous species allometric model used by Ali etal., 2017 was applied. For the remaining species the allometric equation developed by Chave et al. (2005) was used. Table 8 presents the allometric models applied for Above Ground Biomass estimation in Punjab.

Table 8: Allometric models applied for Above Ground Biomass estimation

Sr. No	*Species Type*	Allometric Equation	Reference/ Province
1	*Abies pindrow*	M= 0.0495(D^2H)^0.8935	Ali 2020 (KP)
2	*Acacia modesta*	M= 0.2267(D^2H)^0.8226	Ali 2019 (Sindh & Punjab)
3	*Accacia nilotica Acacia senegal*	M= 0.0569(D^2*H)^0.9745	Ali 2019 (Sindh & Punjab)
4	*Cedrus deodara*	M= 0.0458(D^2H)^0.92	Ali 2020 (KP)
5	*Dodonea viscosa*	M= 0.928(D)^02.018	Ali 2020 (KP)
6	*Eucalyptus camaldulensis*	M= 0.023(D^2*H)^0.9985	Ali 2020 (KP)
7	*General (Coniferous)*	M=0.1645*(WD*DBH^2*H) ^0.8586	Ali et al. 2017 (GB)
8	*Olea ferruginea*	M= 7.8863+0.0556(D^2H)	Ali 2019 (Sindh & Punjab)
9	*Olea ferruginea*	M= 7.8863+0.0556(D^2H)	Ali 2020 (KP)
10	*Other Mix*	M=0.0673*(WD*DBH^2*H) ^0.976	Chave et al, 2014, RFEL/NFMS, 2020
11	*Other species*	M=Exp (-2.187+0.916*ln (WD*D^2*H))	RFEL/NFMS, 2020
12	*Picea smithiana*	M= 0.0821(D^2H)^0.8363	Ali 2020 (KP)
13	*Pinus roxburghii*	M= 0.0224(D^2H)^0.9767	Ali 2020 (KP)
14	*Pinus wallichiana*	M= 0.0594(D^2*H)^0.881	Ali 2020 (KP)
15	*Populous deltodes Populous celiata*	M= 0.0194(D^2H)^0.9654	Ali 2020 (KP)
15	*Populus euphratica*	Height=3.5097*LnD-1.4113	Ali 2019 (Sindh & Punjab
16	*Quercus ilex/ Quercus incana*	M= 0.0795(D^2H)^ 0.9688	Ali 2020 (KP)
17	*Robinea pseudoacacia*	M= 0.2586(D^2H)^0.7786	Ali 2020 (KP)
18	*Tamarix dioca*	M=0.477*(D^2*H)^0.5755	Ali 2019 (Sindh & Punjab)
19	*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 emissions assessment 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 other 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**
Moist-Temperate Forests	2.1	6.4	0
Subtropical Chir Pine Forests	2.1	6.3	0
Subtropical broad leaved (Scrub)	1.8	4.1	0
Tropical Thorn Forests	1.8	4.1	0
Riverine 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 calculations from Enhancement

Removal or sequestration of CO_2 occurs when an area is reforested or afforested or its forest cover is improved resulting in enhancement of carbon stock. Removal Factors are the opposite of Emission Factors of deforestation or forest degradation. Removal factors were calculated both for the normal age of a forest and for the reporting period of four years. Mean age of different forest types were taken from Ali, 2018; Ali, 2019 and; Ali, 2020.

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. Removals were calculated both for mean age of forest and four years using the following formulae.

$$Removals\ (for\ the\ mean\ age\ of\ forest) = RF1 * AD$$

$$Removals\ (for\ four\ years) = RF2 * AD$$

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

Enhancement	Term	Variable Definition/Formula
Non-Forest 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)
	RF1 (for the mean age of forest)	(A-B) x 3.67 (ton CO2e/ ha)
	RF2 (for four years)	(RF1/mean age of forest) x 4 (ton CO2e/ ha)
Sparse Moist Temperate Forest converted to Dense Moist Temperate Forest	A	Forest carbon density in Dense Moist Temperate Forest, mean AGC+BGC+Dead wood+litter (ton C/ha)
	B	Forest carbon density in Sparse Moist Temperate, mean AGC+BGC+Dead wood+litter (ton C/ha)
	RF	(A-B) x 3.67
	RF	**Removal Factor (ton CO_2-eq/ha)**

4. RESULTS

4.1. Forest Type Wise Carbon Stock

As mentioned in the methodology section and also given in Annex-9, the forest carbon stock was assessed using carbon densities calculated from the forest inventory. The total carbon stock in Punjab's forests was estimated as 40.93 million tons for 2020, while in ICT the total carbon stock was found as 1.48 million tons for the same year. The average carbon densities in the forests of Punjab and ICT were estimated as 62.8 t/ha and 57.2 t/ ha respectively. In Punjab the highest carbon density was found in moist temperate forest (121 t/ha), followed by sub-tropical Chir Pine (89.2 t/ha), irrigated plantations (69.0 t/ha), subtropical broad-leaved forests (57 t/ha), riverine forest (42.2 t/ha) and tropical thorn forest (35.2 t/ha). The total carbon stocks for 2016 and 2020 include soil organic carbon and irrigated plantations. Total carbon stocks and carbon densities in different forest types are shown in Table 13 and Table 14. Pool wise forest carbon densities are given as Annex-9.

Table 13: Carbon stocks in different forest types (Punjab)

Forest Type	2016	2020		
	Area (ha)	Area (ha)	C Density (tC/ha)	Carbon Stock (Mt C)
Moist Temperate	1,291	1,199	120.92	0.14
Sub-tropical Chir Pine	132,585	134,267	89.15	11.97
Subtropical broad leaved (Scrub)	386,659	403,334	57.01	22.99
Tropical Thorn	36,097	35,248	35.24	1.24
Riverine	31,982	30,016	42.20	1.27
Irrigated Plantation	45,926	47,936	69.05	3.31
Total	**634539**	**651999**		**40.93**

Table 14: Carbon stocks in different forest types (ICT)

Forest Type	2016	2020		
	Area (ha)	Area (ha)	C Density (tC/ha)	Carbon Stock (Mt C)
Subtropical broad leaved (Scrub)	25,530	25,882	57	1.48
Total	**25,530**	**25,882**		**1.48**

4.2. Emission Factors for Deforestation

Emission factors for different forest types of Punjab (including ICT) are given in Table 15. 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-12.

Table 15: Emission Factors for Deforestation (excluding soil organic carbon)

Forest type	Mean Carbon Density (t C/ha)	SE (%)	Emission Factor (EF) (CO_2e t/ha)				
			Forest-Cropland	Forest-Grassland	Forest-wetland	Forest-Settlement	Forest-Other land
Moist-Temperate Forests	69.1	12.2	245.6	229.8	253.3	253.3	253.3
Subtropical Chir Pine Forests	41.2	16.2	143.3	127.9	151.0	151.0	151.0
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

4.3. Estimates of Deforestation

The total area of deforestation (excluding Irrigated Plantations) in Punjab during 2016-2020 was determined as 6,655 ha while in ICT the deforestation was estimated 448 ha. The average annual deforestation rate was calculated as 1664 ha in Punjab and 112 ha in ICT for the reference period of 2016-2020. In Punjab the highest deforestation was found in sub-tropical broadleaved scrub forest (2438 ha), followed by Tropical Thorn Forests (2139 ha). In ICT the only forest type is the subtropical broad-leaved (scrub) forest and all of the deforestation occurred here. Deforestation estimates of different forest types are given in Table 16 and Table 17. The land use maps of Punjab and ICT for 2016 and 2020 are given in Annex-3, 4 and 5.

Table 16: Estimates of deforestation in different forest types (Punjab)

Forest type	Forest-Cropland (ha)	Forest-Grassland (ha)	Forest-wetland (ha)	Forest-Settlement (ha)	Forest-Other land (ha)	Total deforestation (ha)	%
Moist-Temperate Forests	0	0	0	0	0	0	0
Subtropical Chir Pine Forests	74	9	10	8	25	125	2
Subtropical broad leaved (Scrub)	1485	389	183	15	365	2438	37
Tropical Thorn Forests	1291	532	205	31	82	2139	32
Riverine	1114	283	432	9	115	1953	29
Total	**3964**	**1212**	**829**	**62**	**588**	**6655**	**100**

Table 17 : Estimates of deforestation in different forest types (ICT)

Forest type	Forest-Cropland (ha)	Forest-Grassland (ha)	Forest-wetland (ha)	Forest-Settlement (ha)	Forest-Other land (ha)	Total deforestation (ha)	%
Subtropical broad leaved (Scrub)	0	96	9	125	218	448	100
Total	0	96	9	125	218	448	100

4.4. Estimates of Forest Degradation

The total area under forest degradation in Punjab during 2016-2020 was estimated as 74,441 ha. The highest degradation was found in subtropical broad-leaved scrub forest (59%) followed by subtropical Chir pine forest and (29%). In ICT the degradation occurred in the sub-tropical broad leaved (Scrub) forests (2,148 ha). Estimates of forest degradation in different forest types are given in Table 18.

Table 18: Estimates of Forest Degradation

Forest Type	Punjab		ICT	
	Total degradation (ha)	Percentage (%)	Total degradation (ha)	Percentage (%)
Moist Temperate	476	0.6	---	---
Sub-tropical Chir Pine	21,771	29.2	---	---
Subtropical broad leaved (Scrub)	44,054	59.2	2148	100.0
Tropical Thorn	4,180	5.6	---	---
Riverine	3,961	5.3	---	---
Total	**74,441**	**100.0**	**2148**	**100.0**

4.5. Estimates of Enhancement

The total area of forest enhancement due to reforestation and afforestation in Punjab during 2016-2020 was estimated as 3,752 ha in Punjab and 388 ha in ICT. The average annual enhancement rate was calculated as 938 ha in Punjab and 97 ha in ICT for the period. In Punjab the highest enhancement was found in tropical thorn forest (68%) followed by riverine forest (23%). Enhancement estimates of different forest types are given in Table 19 and Table 20.

Table 19: Estimates of Enhancements (Punjab)

Forest type	Cropland-Forest	Grassland-Forest	Wetland-Forest	Settlement-Forest	Otherland-Forest	Total	%
Moist Temperate	0	0	0	0	0	0	0.0
Sub-tropical Chir Pine	27	22	3	8	2	62	1.7
Subtropical broad leaved (Scrub)	30	156	43	0	6	235	6.3
Tropical Thorn	355	2090	65	6	49	2564	68.3
Riverine	239	364	194	5	89	892	23.8
Total	**651**	**2632**	**306**	**19**	**145**	**3752**	**100.0**

Table 20: Estimates of Enhancements (ICT)

Forest type	Cropland-Forest	Grassland-Forest	Wetland-Forest	Settlement-Forest	Otherland-Forest	Total	%
Subtropical broad leaved (Scrub)	0.0	357.0	24.0	0.0	7.0	388	100.0
Total	**0.0**	**357.0**	**24.0**	**0.0**	**7.0**	**388**	**100.0**

4.6. Emissions from Deforestation

The total emissions from deforestation in Punjab and ICT were estimated as 0.163 and 0.015 million tons of CO2e respectively between 2016 and 2020 Table 21 and Table 22). In Punjab the largest share of CO2 emissions originated from tropical Subtropical broad leaved (Scrub) forest (46%), followed by subtropical thorn forest (26%) as shown in Figure 5.

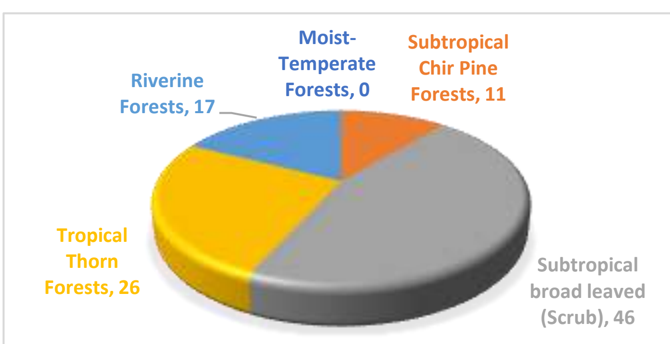

Figure 5: Forest type wise distribution of Emissions from Deforestation (in percentage)

Table 21: Emissions from Deforestation (Punjab)

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)		
Moist-Temperate Forests	0	245.6	0.000	0	229.8	0.000	0	253.3	0.000	0	253.3	0.000	0	253.3	0.000	0	0.000
Subtropical Chir Pine Forests	74	143.3	0.011	9	127.9	0.001	10	151.0	0.001	8	151.0	0.001	25	151.0	0.004	125	0.018
Subtropical broad leaved (Scrub)	1485	30.3	0.045	389	21.9	0.008	183	36.9	0.007	15	36.9	0.001	365	36.9	0.013	2438	0.074
Tropical Thorn Forests	1291	20.7	0.027	532	12.3	0.007	205	27.3	0.006	31	27.3	0.001	82	27.3	0.002	2139	0.042
Riverine Forests	1114	13.9	0.015	283	5.4	0.002	432	20.5	0.009	9	20.5	0.000	115	20.5	0.002	1953	0.028
Total	**3964**		**0.098**	**1212**		0.018	**829**		**0.023**	**62**		**0.003**	**588**		**0.022**	**6655**	**0.163**

Table 22: Emissions from Deforestation (ICT)

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)	0	30.3	0.000	96	21.9	0.0021	9	36.9	0.0003	125	36.9	0.0046	218	36.9	0.0080	448	0.0151
Total	**0**		**0.000**	**96**		0.0021	**9**		**0.0003**	**125**		**0.0046**	**218**		**0.0080**	**448**	**0.0151**

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. Emission factors for forest degradation are given in Table 23. Uncertainty of the EFs/ Carbon Densities for the four canopy classes are given as Annex-13.

Table 23: Emissions 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)
Moist Temperate	51.3	188.3	73.7	270.2	92.4	338.9	22.3	81.9	41.1	150.7	18.7	68.7
Sub-tropical Chir Pine	12.9	47.3	32.5	119.3	45.4	166.5	19.6	72.0	32.5	119.2	12.9	47.2
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
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 degradations and improvement in forest cover density

Total emissions from forest degradation in Punjab were estimated as 2.49 million tons CO_2e during 2016-2020 and the total enhancement from improvement in canopy cover was estimated as 0.97 million tons CO_2e during this period. Thus, the net balance is emissions of 1.51 million tons of CO_2e. In ICT the total emissions from forest degradation were estimated as 0.065 million tons CO_2e during 2016-2020 while total enhancement was estimated as 0.071 million tons CO_2e with a net balance of removals as 0.005 million tons CO_2e. Details of forest type wise degradation and enhancement are given in Table 24 and Table 25. Detailed forest type and canopy cover class wise emissions from forest degradation and removals from enhancement in cover densities are given as Annex-10 and 11.

Table 24: Emissions from Forest Degradation and Improvement in forest cover density (Punjab)

Forest Type	Total degradation (ha)	Emissions (Mt CO2e)	Total improvement in forest cover density (ha)	Removals (Mt CO2e)	Net Emissions/ Removals (Mt CO2e)
Moist Temperate	476	0.070	20	0.004	0.066
Sub-tropical Chir Pine	21,771	1.167	1,942	0.093	1.074
Subtropical broad leaved (Scrub)	44,054	1.190	50,491	0.877	0.313
Tropical Thorn*	4,180	0.047	1,727	0.006	0.041
Riverine*	3,961	0.021	2,580	0.007	0.014
Total	**74,441**	**2.494**	**56,760**	**0.986**	1.508

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

Table 25: Emissions from Forest Degradation and Improvement in forest cover density (ICT)

Forest Type	Total degradation (ha)	Emissions (Mt CO2e)	Total improvement in forest cover density (ha)	Removals (Mt CO2e)	Net Emissions/ Removals (Mt CO2e)
Subtropical broad leaved (Scrub)	2,148	0.065	2,362	0.071	-0.005
Total	**2,148**	**0.065**	**2,362**	**0.071**	**-0.005**

4.9. Removals from Enhancement

Removals from enhancement due to reforestation and afforestation were estimated both for the normal age of each forest type and for the reporting period of four years. The total removals from enhancement for the normal age of forest were estimated as 0.062 million tons of CO_2e in Punjab and 0.01 million tons of CO_2e in ICT. While the total removals from enhancement for the reporting period of four years (2016-2020) was estimated as 0.013 million tons of CO_2e in Punjab and 0.0021 million tons of CO_2e in ICT. In Punjab the largest share of CO_2 removal was found in Riverine Forest (50%), followed by Sub-Tropical Thorn Forest (33%) and subtropical Broad Leaved (Scrub) forests (11%). Details shown in Table 26, Table 27, Table 28, Table 29 and Figure 6.

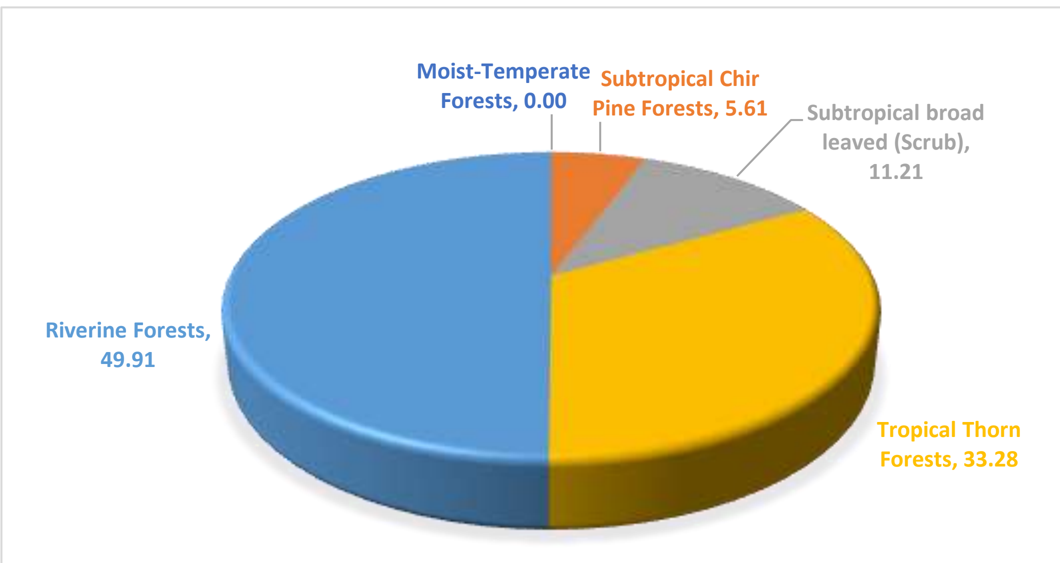

Figure 6: Forest type wise distribution of removals from enhancement in percent (Punjab)

Table 26: Removals from enhancement (for the mean age of forest) (Punjab)

Forest type	Cropland-Forest			Grassland-Forest			Wetland-Forest			Settlement-Forest			Otherland-Forest			Total Enh. (ha)	Total Rem. (Mt CO2e)
	Enh. (ha)	RF (CO2e t/ha)	Rem. (Mt CO2e)	Enh. (ha)	RF (CO2e t/ha)	Enh. (ha)	RF (CO2e t/ha)	RF (CO2e t/ha)	Rem. (Mt CO2e)	Enh. (ha)	RF (CO2e t/ha)	Rem. (Mt CO2e)	Enh. (ha)	RF (CO2e t/ha)	Rem. (Mt CO2e)		
Moist-Temperate Forests	0	245.6	0.000	0	229.8	0.000	0	253.3	0.000	0	253.3	0.000	0	253.3	0.000	0	0.000
Subtropical Chir Pine Forests	27	143.3	0.004	22	127.9	0.003	3	151.0	0.000	8	151.0	0.001	2	151.0	0.000	62	0.009
Subtropical broad leaved (Scrub)	30	30.3	0.001	156	21.9	0.003	43	36.9	0.002	0	36.9	0.000	6	36.9	0.000	235	0.006
Tropical Thorn Forests	355	20.7	0.007	2090	12.3	0.026	65	27.3	0.002	6	27.3	0.000	49	27.3	0.001	2564	0.036
Riverine Forests	239	13.9	0.003	364	5.4	0.002	194	20.5	0.004	5	20.5	0.000	89	20.5	0.002	892	0.011
Total	651		0.015	2632		0.034	306		0.008	19		0.001	145		0.004	3752	0.062

Table 27: Removals from enhancement (for the mean age of forest) (ICT)

Forest type	Cropland-Forest			Grassland-Forest			Wetland-Forest			Settlement-Forest			Otherland-Forest			Total Enh. (ha)	Total Rem. (Mt CO2e)
	Enh. (ha)	RF (CO2e t/ha)	Rem. (Mt CO2e)	Enh. (ha)	RF (CO2e t/ha)	Enh. (ha)	RF (CO2e t/ha)	RF (CO2e t/ha)	Rem. (Mt CO2e)	Enh. (ha)	RF (CO2e t/ha)	Rem. (Mt CO2e)	Enh. (ha)	RF (CO2e t/ha)	Rem. (Mt CO2e)		
Subtropical broad leaved (Scrub)	0	30.3	0.000	357	21.9	0.0078	24	36.9	0.0009	0	36.9	0	7	36.9	0.0003	388	0.009
Total	**0**		**0.000**	**357**		**0.0078**	**24**		**0.0009**	**0**		**0**	**7**		**0.0003**	**388**	**0.009**

Table 28: Removals from enhancement (for four years) (Punjab)

Forest type	Cropland-Forest			Grassland-Forest			Wetland-Forest			Settlement-Forest			Otherland-Forest			Total Enh (ha)	Total Rem (Mt CO2e)
	Enh (ha)	RF (CO2e t/ha)	Rem (Mt CO2e)	Enh (ha)	RF (CO2e t/ha)	Rem (Mt CO2e)	Enh (ha)	RF (CO2e t/ha)	Rem (Mt CO2e)	Enh (ha)	RF (CO2e t/ha)	Rem (Mt CO2e)	Enh (ha)	RF (CO2e t/ha)	Rem (Mt CO2e)		
Moist-Temperate Forests	0	15.59	0.000	0	14.59	0.000	0	16.08	0.000	0	16.08	0.000	0	16.08	0.000	0	0.001
Subtropical Chir Pine Forests	27	11.94	0.000	22	10.66	0.000	3	12.58	0.000	8	12.58	0.000	2	12.58	0.000	62	0.001
Subtropical broad leaved (Scrub)	30	7.13	0.000	156	5.14	0.001	43	8.68	0.000	0	8.68	0.000	6	8.68	0.000	235	0.001
Tropical Thorn Forests	355	2.44	0.001	2090	1.45	0.003	65	3.21	0.000	6	3.21	0.000	49	3.21	0.000	2564	0.004
Riverine Forests	239	7.93	0.002	364	3.11	0.001	194	11.70	0.002	5	11.70	0.000	89	11.70	0.001	892	0.006
Total	**651**		**0.003**	**2632**		**0.005**	**306**		**0.003**	**19**		**0.000**	**145**		**0.001**	**3752**	**0.013**

Table 29: Removals from enhancement (for four years) (ICT)

Forest type	Cropland-Forest			Grassland-Forest			Wetland-Forest			Settlement-Forest			Otherland-Forest			Total Enh (ha)	Total Rem (Mt CO2e)
	Enh (ha)	RF (CO2e t/ha)	Rem (Mt CO2e)	Enh (ha)	RF (CO2e t/ha)	Rem (Mt CO2e)	Enh (ha)	RF (CO2e t/ha)	Rem (Mt CO2e)	Enh (ha)	RF (CO2e t/ha)	Rem (Mt CO2e)	Enh (ha)	RF (CO2e t/ha)	Rem (Mt CO2e)		
Subtropical broad leaved (Scrub)	30	7.13	0.000	357	5.14	0.002	24	8.68	0.000	37	8.68	0.000	7	8.68	0.000	455	0.0021
Total	**30**		**0.000**	**357**		**0.002**	**24**		**0.000**	**37**		**0.000**	**7**		**0.000**	**455**	**0.0021**

4.10. Overall situation of emissions and removals

Keeping in view the overall situation, a net balance of 1.66 and 0.007 million tons of CO_2e were emitted from deforestation, and forest degradation during 2016 to 2020 in Punjab and ICT respectively. The overall pictures of emissions and removals from deforestation, forest degradation and enhancement in Punjab and ICT are given in Table 30 and Table 31 below.

Table 30: Overall carbon emissions and removals during the reporting period 2016-2020 (Punjab)

Forest Type	Emissions from deforestation (Mt CO2e)	Emissions from forest degradation for 4 years (Mt CO2e)	Removals from enhancement (Mt CO2e)	Removals from improvement in growing stock (Mt CO2e)	Net balance (Mt CO2e)
Moist-Temperate Forests	0	0.07	0.000	0.004	0.066
Subtropical Chir Pine Forests	0.018	1.167	0.001	0.093	1.091
Subtropical broad leaved (Scrub)	0.074	1.19	0.001	0.877	0.386
Tropical Thorn Forests	0.042	0.047	0.004	0.006	0.079
Riverine Forests	0.028	0.021	0.006	0.007	0.036
Total	**0.162**	**2.495**	**0.013**	**0.987**	**1.657**

Table 31: Overall carbon emissions and removals during the reporting period 2016-2020 (ICT)

Forest Type	Emissions from deforestation (Mt CO2e)	Emissions from forest degradation for 4 years (Mt CO2e)	Removals from enhancement (Mt CO2e)	Removals from improvement in growing stock (Mt CO2e)	Net balance (Mt CO2e)
Subtropical broad leaved (Scrub)	0.015	0.065	0.003	0.071	0.007
Total	**0.015**	0.065	**0.003**	0.071	**0.007**

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.

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 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.

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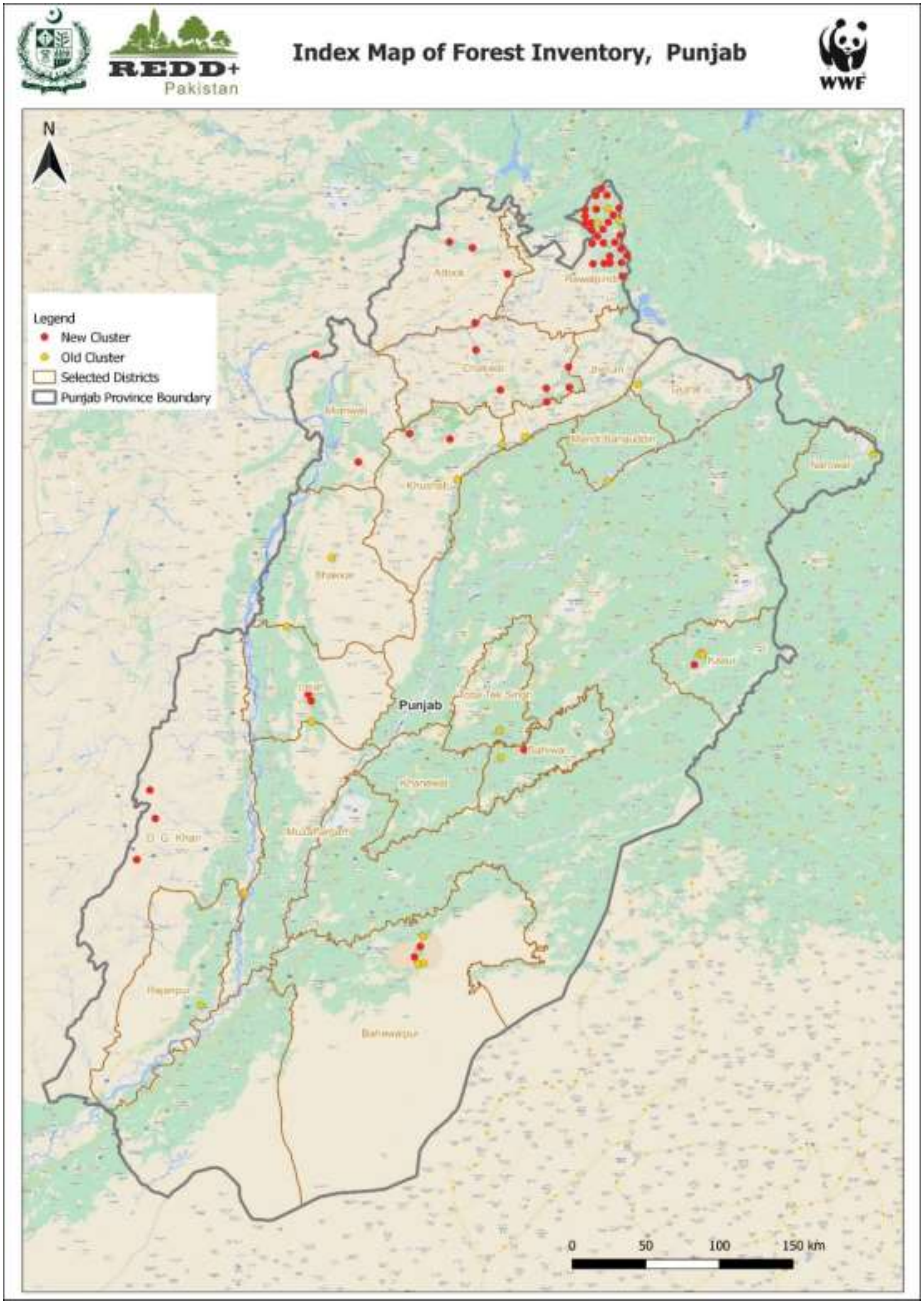
7. ANNEXES

Annex 1. Forest Inventory Plots Location Map (Punjab)

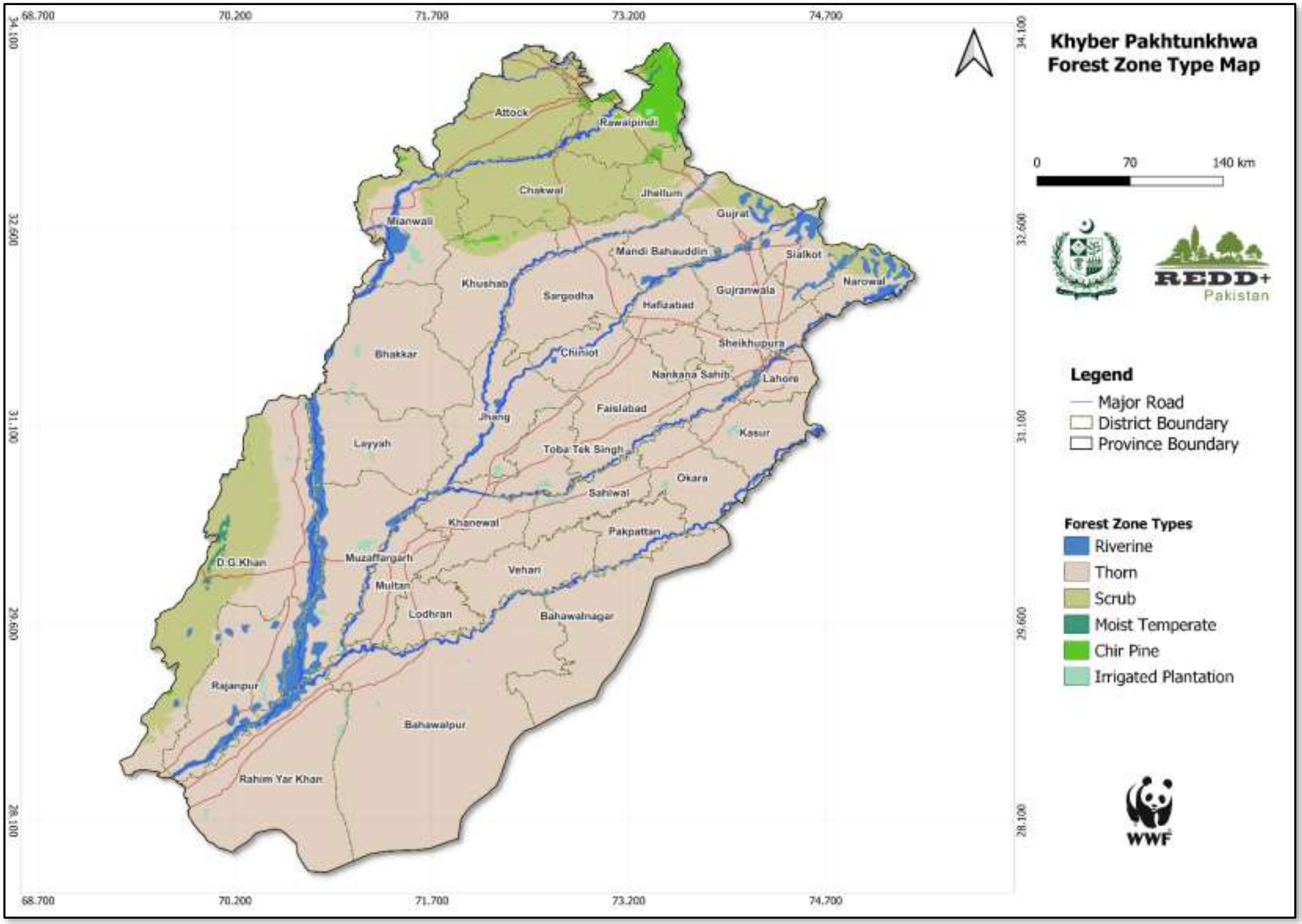


Annex-2: Coordinates of forest inventory sample plots (clusters) in Punjab

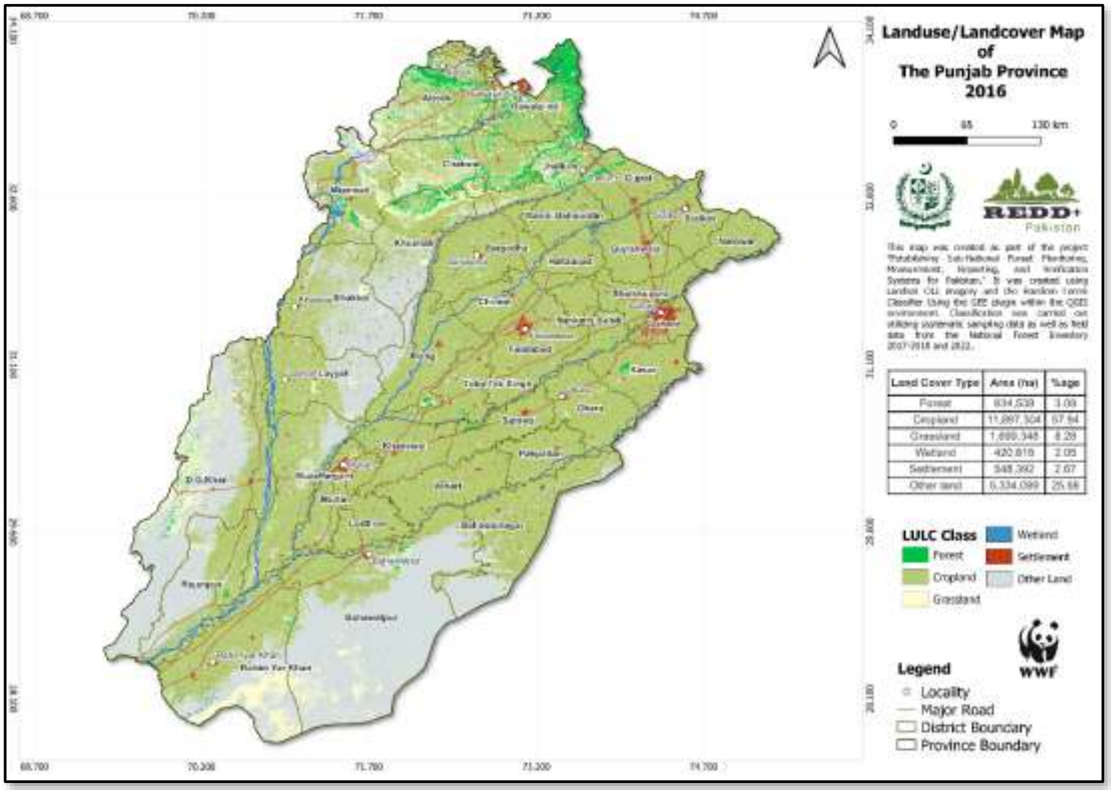
Cluster No	Cluster ID	Cluster Plot	Latitude (UTM)	Longitude (UTM)	UTM-Proj.	Elevation	Slope	Aspect
574	ChP574	ChP574-5	3749810	918638.8	EPSG: 32642	1196	6.4625	245.55
573	PMT573	PMT573-5	3358796	603818.6	EPSG: 32642	1319	8.81457	291.8014
572	PMT572	PMT572-5	3339461	607434.9	EPSG: 32642	1893	24.20312	52.53944
571	PMT571	PMT571-5	3311473	594854.4	EPSG: 32642	1754	20.90466	329.9314
570	PP570	PP570-5	3212644	638299	EPSG: 32642	101	5.30278	233.1301
569	PP569	PP569-5	3289240	667998	EPSG: 32642	112	1.42654	180
568	PP568	PP568-5	3240787	785799	EPSG: 32642	126	0.36771	135
567	PTh567	PTh567-5	3240889	789849	EPSG: 32642	127	3.16334	285.2551
566	PTh566	PTh566-5	3245356	783658.4	EPSG: 32642	130	0.87429	71.56505
565	PTh565	PTh565-5	3252388	787531.9	EPSG: 32642	132	4.6983	290.556
564	PP564	PP564-5	3259369	789377	EPSG: 32642	130	4.76923	315
563	PP563	PP563-5	3451229	979464.3	EPSG: 32642	200	0.87429	251.5651
562	PP562	PP562-5	3451139	977474.8	EPSG: 32642	204	0.36771	315
561	PP561	PP561-5	3444021	973804.9	EPSG: 32642	199	3.16334	74.74488
560	PP560	PP560-5	3399607	841678.5	EPSG: 32642	154	2.95896	68.19859
559	PP559	PP559-5	3386260	858118.7	EPSG: 32642	164	1.93231	236.3099
558	PP558	PP558-5	3381119	842244.7	EPSG: 32642	157	0.76652	18.43495
557	PP557	PP557-5	3363535	794691	EPSG: 32642	144	1.10416	333.4349
556	PP556	PP556-5	3405536	713719	EPSG: 32642	147	2.08795	293.1986
555	PP555	PP555-5	3419400	713426.7	EPSG: 32642	148	3.02088	307.875
554	PTh554	PTh554-5	3423980	711343	EPSG: 32642	151	0.36771	135
553	PP553	PP553-5	3469900	696545	EPSG: 32642	161	1.86454	336.8014
552	PP552	PP552-5	3516737	727245	EPSG: 32642	180	0.36771	135
551	PR551	PR551-5	3569873	812542.1	EPSG: 32642	172	4.20616	273.8141
550	PP550	PP550-5	3567141	798858.9	EPSG: 32642	187	3.65998	168.6901
549	PP549	PP549-5	3581890	745422.1	EPSG: 32642	201	2.74574	195.2551
548	PScrb548	PScrb548-5	3655187	716351.5	EPSG: 32642	761	27.60115	209.3319
547	PScrb547	PScrb547-5	3601266	780265	EPSG: 32642	838	22.70606	199.5367
546	PScrb546	PScrb546-5	3597481	807764.6	EPSG: 32642	490	1.103	315
545	PP545	PP545-5	3593998	843182.4	EPSG: 32642	188	1.74818	71.56505
544	PR544	PR544-5	3599181	858709.6	EPSG: 32642	184	0	0
543	PP543	PP543-5	3595725	890240.9	EPSG: 32642	207	1.90174	0
542	PR542	PR542-5	3568918	914911.2	EPSG: 32642	199	0.76652	18.43495
541	PScrb541	PScrb541-5	3587224	1095398	EPSG: 32642	265	0	0
540	PScrb540	PScrb540-5	3634660	935683.2	EPSG: 32642	281	4.82149	23.96249
539	PScrb539	PScrb539-5	3642913	911852.6	EPSG: 32642	730	17.25711	261.8699
538	PScrb538	PScrb538-5	3646588	888248.9	EPSG: 32642	613	26.3472	93.96465
537	PScrb537	PScrb537-5	3632716	888795	EPSG: 32642	748	10.6828	311.0548

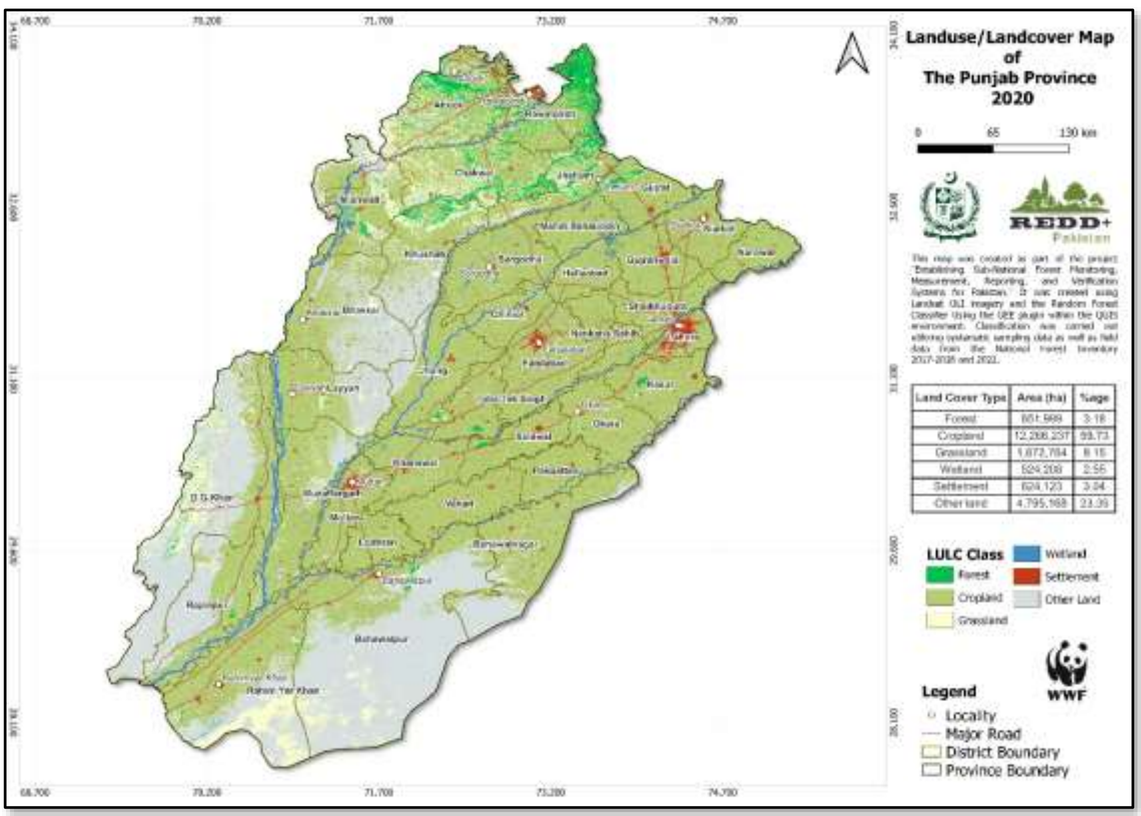
Cluster No	Cluster ID	Cluster Plot	Latitude (UTM)	Longitude (UTM)	UTM-Proj.	Elevation	Slope	Aspect
536	PScrb536	PScrb536-5	3632115	873167.9	EPSG: 32642	753	21.05517	6.20345
535	PScrb535	PScrb535-5	3622867	873515.9	EPSG: 32642	634	17.27633	7.69605
534	PScrb534	PScrb534-5	3630987	841917.6	EPSG: 32642	806	6.58964	315
533	PScrb533	PScrb533-5	3658195	825377.7	EPSG: 32642	378	13.40902	232.9072
532	PScrb532	PScrb532-5	3676686	824763.2	EPSG: 32642	381	9.38333	220.6013
531	PScrb531	PScrb531-5	3709854	846928.1	EPSG: 32642	553	9.45747	305.9097
530	PScrb530	PScrb530-5	3727538	823059.1	EPSG: 32642	623	27.13091	4.18491
529	PScrb529	PScrb529-5	3731651	807443.9	EPSG: 32642	368	9.72477	268.3634
528	PChP528	PChP528-5	3708331	924641.5	EPSG: 32642	742	14.61043	40.81508
527	PChP527	PChP527-5	3717581	924234	EPSG: 32642	767	15.90781	275.9061
526	PChP526	PChP526-5	3717243	916485.3	EPSG: 32642	765	19.63412	138.0665
525	PChP525	PChP525-5	3717076	912611.1	EPSG: 32642	722	12.26883	308.0888
524	PP524	PP524-5	3716747	904862.9	EPSG: 32642	652	13.54036	198.435
523	PChP523	PChP523-5	3721899	916303.2	EPSG: 32642	762	17.37501	293.4287
522	PChP522	PChP522-5	3722378	927902.5	EPSG: 32642	750	27.08971	50.85601
521	PChP521	PChP521-5	3726832	923825.6	EPSG: 32642	734	6.76659	241.3895
520	PChP520	PChP520-5	3731287	919752.3	EPSG: 32642	905	17.29102	211.2392
519	PChP519	PChP519-5	3730951	912015.1	EPSG: 32642	882	29.25138	154.0256
518	PChP518	PChP518-5	3730621	904278.1	EPSG: 32642	887	10.12817	209.0546
517	PChP517	PChP517-5	3736083	923416.4	EPSG: 32642	732	10.32814	49.08562
516	PChP516	PChP516-5	3735410	907949.3	EPSG: 32642	755	5.2441	158.1986
515	PChP515	PChP515-5	3740201	911616.6	EPSG: 32642	928	36.72948	282.0426
514	PChP514	PChP514-5	3745539	923199.2	EPSG: 32642	639	25.20312	22.38013
513	PChP513	PChP513-5	3744993	915280.1	EPSG: 32642	1268	8.10827	186.7098
512	PChP512	PChP512-5	3744661	907551.2	EPSG: 32642	1320	16.76528	152.7004
511	PChP511	PChP511-5	3744496	903691.4	EPSG: 32642	893	23.37449	7.19347
510	PScrb510	PScrb510-5	3744333	899828.7	EPSG: 32642	737	13.56918	310.3645
509	PChP509	PChP509-5	3748958	899634.6	EPSG: 32642	947	19.3775	259.6242
508	PChP508	PScrb508-5	3739871	903886.9	EPSG: 32642	845	10.32814	229.0856
507	PChP507	PChP507-5	3754652	922595.2	EPSG: 32642	767	25.12799	359.493
506	PChP506	PChP506-5	3754252	914875.9	EPSG: 32642	2120	15.7169	43.69805
505	PChP505	PChP505-5	3753910	907158.3	EPSG: 32642	1231	21.6484	224.076
504	PChP504	PChP504-5	3753588	899426.4	EPSG: 32642	1173	21.14984	285.2551
503	PChP503	PChP503-5	3763494	914472.2	EPSG: 32642	1226	28.15358	29.68718
502	PChP502	PChP502-5	3763205	906874.4	EPSG: 32642	2070	29.88894	43.09085
501	PChP501	PChP501-5	3767951	910416.2	EPSG: 32642	1271	6.70051	270

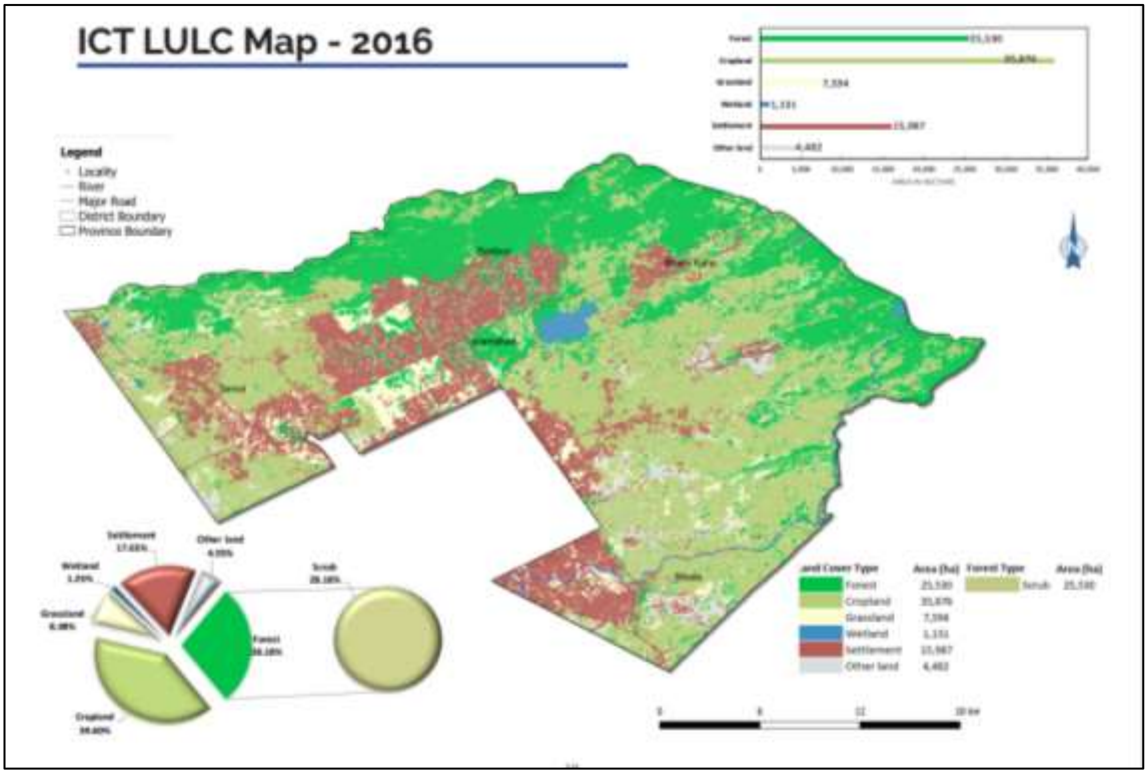
Annex-3: Forest Types Map of Punjab

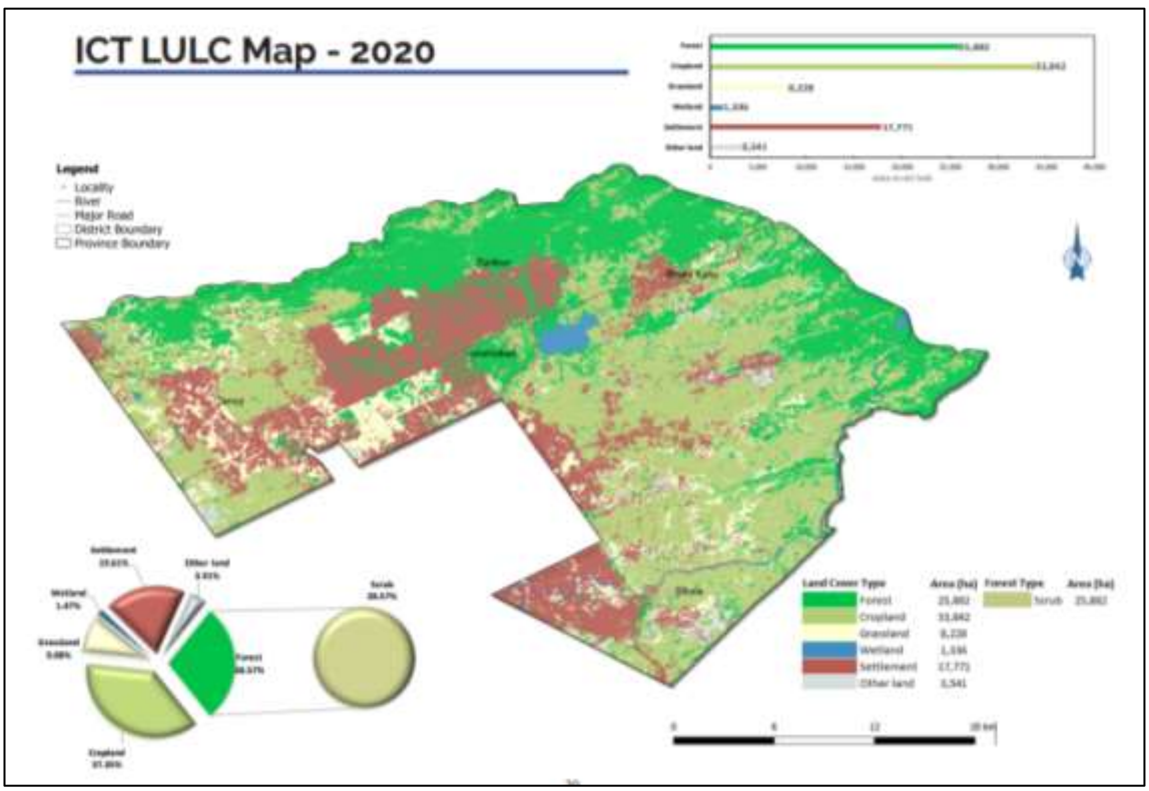


Annex-4: LULC Maps 2016 and 2020 of Punjab and ICT

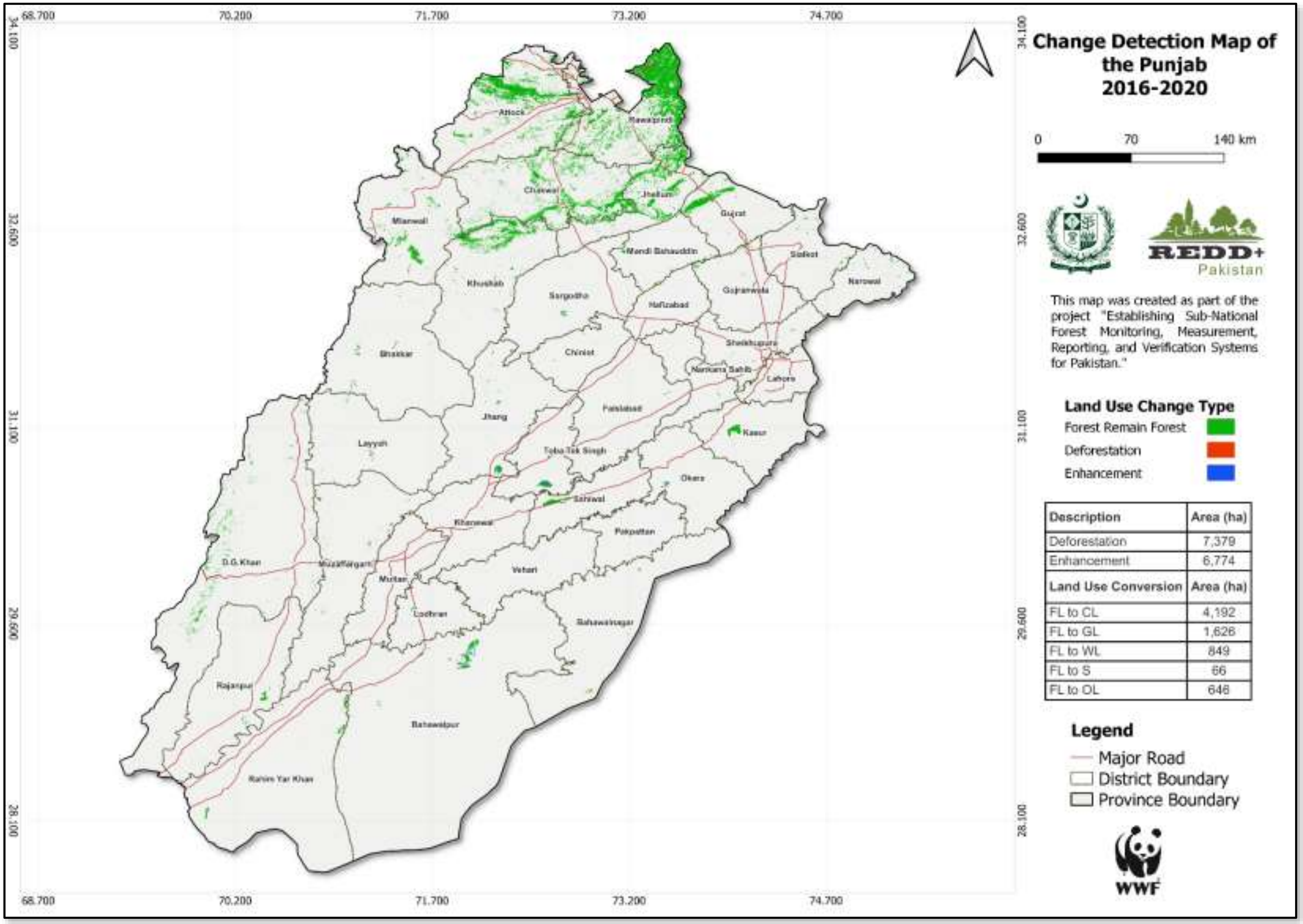


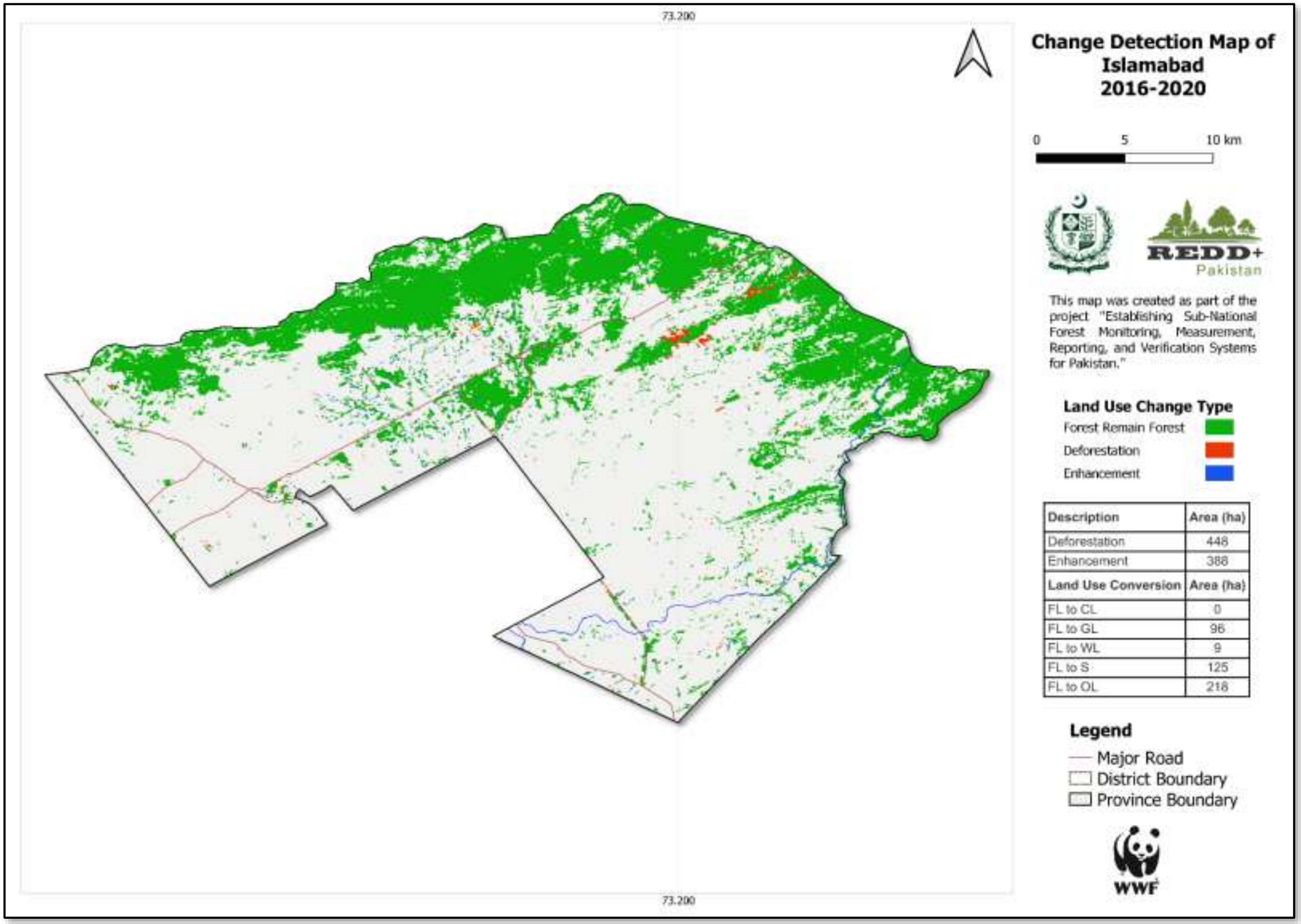



ICT LULC Map - 2016
Legend
Locality
River
Major Road
District Boundary
Province Boundary


ICT LULC Map - 2020
Legend
Locality
River
Major Road
District Boundary
Province Boundary

Annex 5. Land Use Land Cover Change Map of Punjab and ICT




73.200
Change Detection Map of Islamabad 2016-2020
0
5
10 km
REDD+ Pakistan
This map was created as part of the project "Establishing Sub-National Forest Monitoring, Measurement, Reporting, and Verification Systems for Pakistan."
Land Use Change Type
Forest Remain Forest
Deforestation
Enhancement
Description | Area (ha)
Deforestation | 448
Enhancement | 388
Land Use Conversion | Area (ha)
FL to CL | 0
FL to GL | 96
FL to WL | 9
FL to S | 125
FL to OL | 218
Legend
Major Road
District Boundary
Province Boundary
WWF
73.200

Annex-6. 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-7: Revised Forest measurement manual (provided as separate file)

Annex-8: Data Storage and Processing report (provided as separate file)

Annex-9: 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
Moist Temperate	55.20	13.80	0.09	0.00	**69.08**	51.83	**120.92**
Sub-tropical Chir Pine	32.91	8.23	0.03	0.00	**41.17**	47.98	**89.15**
Subtropical broad leaved (Scrub)	8.03	2.01	0.02	0.00	**10.06**	46.95	**57.01**
Tropical Thorn	5.95	1.49	0.01	0.01	**7.45**	27.79	**35.24**
Riverine	4.46	1.12	0.00	0.00	**5.58**	36.62	**42.20**
Irrigated Plantation	17.95	4.49	0.05	0.03	**22.52**	46.53	**69.05**

Annex-10: Details of emissions from forest degradations

Forest Type	Dense - Medium			Dense - Sparse			Dense - Open			Medium - Sparse			Medium - Open			Sparse - Open			Total	
	EF CO2e (t/ha)	Deg. (ha)	Emis (Mt CO2e)	EF CO2e (t/ha)	Deg. (ha)	Emis (Mt CO2e)	EF CO2e (t/ha)	Deg. (ha)	Emis (Mt CO2e)	EF CO2e (t/ha)	Deg. (ha)	Emis (Mt CO2e)	EF CO2e (t/ha)	Deg. (ha)	Emis (Mt CO2e)	EF CO2e (t/ha)	Deg. (ha)	Emis (Mt CO2e)	Deg. (ha)	Emis (Mt CO2e)
Sub-Alpine	72.60	0	0.00	187.82	0	0.00	213.09	0	0.00	115.22	0	0.00	140.49	0	0.00	25.27	0	0.00	0	0.00
Dry Temperate	107.77	0	0.00	210.15	0	0.00	321.13	0	0.00	102.38	0	0.00	213.36	0	0.00	110.98	0	0.00	0	0.00
Dry temperate Juniper and Chilghoza Forests	100.08	0	0.00	141.09	0	0.00	181.67	0	0.00	41.01	0	0.00	81.59	0	0.00	40.58	0	0.00	0	0.00
Moist Temperate	188.26	236	0.04	270.16	31	0.01	338.91	0	0.00	81.91	178	0.01	150.66	3	0.00	68.75	27	0.00	475	0.07
Sub-tropical Chir Pine	47.33	17023	0.81	119.29	397	0.05	166.53	8	0.00	71.96	3994	0.29	119.20	125	0.01	47.24	224	0.01	21771	1.17
Subtropical broad leaved (Scrub)	16.37	33733	0.55	77.65	841	0.07	100.91	34	0.00	61.28	9003	0.55	84.54	108	0.01	23.26	335	0.01	44054	1.19
Tropical Thorn	-	2998	-	-	310	-	-	50	-	54.55	603	0.03	92.96	97	0.01	38.41	122	0.00	4180	0.05
Riverine	-	2915	-	-	332	-	-	68	-	35.45	502	0.02	43.16	58	0.00	7.72	86	0.00	3960	0.02
Mangroves	22.46	0	0.00	8.71	0	0.00	35.09	0	0.00	-13.75	0	0.00	12.63	0	0.00	26.38	0	0.00	0	0.00
Total		**56905**	**1.40**		**1911**	**0.12**		**160**	**0.00**		**14280**	**0.90**		**391**	**0.04**		**793**	**0.03**	**74440**	**2.49**

Annex-11: Details of removals from forest enhancement in forest cover density

Forest Type	Medium-Dense			Sparse-Dense			Open-Dense			Sparse-Medium			Open-Medium			Open-Sparse			Total	
	RF CO2e (t/ha)$_2$e (t/ha)	Enh (ha)	Rem (Mt CO2e)	RF CO2e (t/ha)$_2$e (t/ha)	Enh (ha)	Rem (Mt CO2e)	RF CO2e (t/ha)$_2$e (t/ha)	Enh (ha)	Rem (Mt CO2e)	RF CO2e (t/ha)$_2$e (t/ha)	Enh (ha)	Rem (Mt CO2e)	RF CO2e (t/ha)$_2$e (t/ha)	Enh (ha)	Rem (Mt CO2e)	RF CO2e (t/ha)$_2$e (t/ha)	Enh (ha)	Rem (Mt CO2e)	Enh (ha)	Rem (Mt CO2e)
Sub-Alpine	72.60	0	0.00	187.82	0	0.00	213.09	0	0.00	115.22	0	0.00	140.49	0	0.00	25.27	0	0.00	0	0.00
Dry Temperate	107.77	0	0.00	210.15	0	0.00	321.13	0	0.00	102.38	0	0.00	213.36	0	0.00	110.98	0	0.00	0	0.00
Dry temperate Juniper and Chilghoza Forests	100.08	0	0.00	141.09	0	0.00	181.67	0	0.00	41.01	0	0.00	81.59	0	0.00	40.58	0	0.00	0	0.00
Moist Temperate	188.26	18	0.00	270.16	0	0.00	338.91	0	0.00	81.91	2	0.00	150.66	0	0.00	68.75	1	0.00	20	0.00
Sub-tropical Chir Pine	47.33	1906	0.09	119.29	3	0.00	166.53	0	0.00	71.96	32	0.00	119.20	1	0.00	47.24	0	0.00	1942	0.09
Subtropical broad leaved (Scrub)	16.37	49430	0.81	77.65	195	0.02	100.91	1	0.00	61.28	851	0.05	84.54	3	0.00	23.26	12	0.00	50491	0.88
Tropical Thorn	-	1495	-	-	116	-	-	7	-	54.55	100	0.01	92.96	5	0.00	38.41	4	0.00	1727	0.01
Riverine	-	2270	-	-	108	-	-	10	-	35.45	159	0.01	43.17	18	0.00	7.72	14	0.00	2580	0.01
Mangroves	22.46	0	0.00	8.71	0	0.00	35.09	0	0.00	-13.75	0	0.00	12.63	0	0.00	26.38	0	0.00	0	0.00
Total		**55119**	**0.90**		**422**	**0.02**		**18**	**0.00**		**1143**	**0.07**		**27**	**0.00**		**31**	**0.00**	**56760**	**0.99**

Annex-12: 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 overall (Forest to wetlands/ settlement/ other land)							
Moist-Temperate Forests	69.08	12.21	443.37	54.13	106.10	337.27	549.46
Subtropical Chir Pine Forests	41.17	16.22	326.89	53.03	103.94	222.95	430.83
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
Irrigated Plantation	22.52	19.84	253.18	50.24	98.46	154.71	351.64
EF deforestation (Forest to cropland)							
Moist-Temperate Forests	69.08	12.21	245.61	29.99	58.77	186.84	304.38
Subtropical Chir Pine Forests	41.17	16.22	143.27	23.24	45.56	97.71	188.82
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
Irrigated Plantation	22.52	19.84	75.97	15.07	29.55	46.43	105.52
EF deforestation (Forest to grassland)							
Moist-Temperate Forests	69.08	12.21	229.84	28.06	55.00	174.84	284.84
Subtropical Chir Pine Forests	41.17	16.22	127.87	20.74	40.66	87.21	168.53
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
Irrigated Plantation	22.52	19.84	67.54	13.40	26.27	41.27	93.81

Annex-13: Uncertainties of Emission Factors of Forest Degradation

Annex-13: (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	
Moist Temperate	51.34	188.26	19.79	37.25	73.02	-53.23	92.81	73.68	270.16	22.18	59.93	117.47	-95.29	139.65
Sub-tropical Chir Pine	12.91	47.33	22.38	10.59	20.76	1.62	43.14	32.53	119.29	24.36	29.06	56.95	-32.59	81.31
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	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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-13: (Part-b)

Forest Type	Dense-Open							Medium-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	
Moist Temperate	92.43	338.91	33.46	338.91	33.46	0.00	66.92	22.34	81.91	14.96	12.25	24.02	-9.06	38.97
Sub-tropical Chir Pine	45.42	166.53	28.12	166.53	28.12	0.00	56.24	19.62	71.96	26.81	19.29	37.81	-11.00	64.61
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
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-13: (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	
Moist Temperate	41.09	150.66	29.18	43.96	86.16	-56.98	115.33	18.75	68.75	30.85	21.21	41.57	-10.72	72.42
Sub-tropical Chir Pine	32.51	119.20	30.26	36.07	70.70	-40.44	100.97	12.88	47.24	31.75	15.00	29.40	2.35	61.16
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
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-14: 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-15: Mean Ages of Different Forest Types

Forest Type	Mean DBH_cm	Mean Age
Subalpine	34	52
Moist Temp	42	63
Dry Temperate	28	85
Dry Temperate Chilghoza	27	80
Subtropical Pine	28	48
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