GREEN HOUSE GAS INVETORY OF FORESTRY SECTOR-KHYBER PAKHTUNKHWA 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)
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)
LCCS	FAO's Land Cover Classification System
LiDAR	Light Detection and Ranging
LULC	Land Use Land Cover
LULUCF	Land Use, Land Use Change and Forestry
MBIGS	Multiple benefits, impacts, governance, safeguards
MMRV	Monitoring & Measurement, Reporting and Verification
MMU	Minimum Mapping Unit
MOCC	Ministry of Climate Change
MOE	Ministry of Environment
MRV	Measurement, Reporting and Verification
MSS	Multispectral Scanner
NASA	National Aeronautics and Space Administration
NCCA	National Climate Change Authority
NFI	National Forest Inventory
NFMS	National Forest Monitoring System
NGO	Non-governmental Organization
NRP	National REDD+ Program
NSC	National REDD+ Steering Committee
NSDI	National spatial data infrastructure
NTFP	Non-Timber Forest Product
NUST	National University of Sciences and Technology (NUST)
O&M	Operationalization and Maintenance
OBIA	Object Based Image Analysis
OGC	Open Geospatial Consortium
OIGF	Office of Inspector General of Forests
OLI	Operational Land Imager
PAMs	REDD+ Policies and Measures
PB	Punjab (province)
PBI	MS Power BI (A Microsoft Data Analysis Software)
PES	Payment of Ecosystem Services
PFI	Pakistan Forest Institute
PSU	Primary Sampling Unit

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

EXECUTIVE SUMMARY

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

The current Sub-National GHG-Inventory Report covers the total area of the KP Province including the newly merged districts (ex FATA), that is 101,741 km².

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 KP the total calculated sample plots were 460 (92 clusters) out which 361 plots (77 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 area of deforestation in Khyber Pakhtunkhwa was determined as 7,832 ha during 2016-2020. The average annual deforestation rate was calculated as 1,958 ha for the reference period of 2016-2020. The highest deforestation was found in dry temperate (3,254 ha) followed by subtropical pine forest (2,058 ha) and Subtropical broad leaved (Scrub) forest (1,130 ha).

The total area under forest degradation in KP during 2016-2020 was estimated as 342,969 ha. The highest degradation was found in dry temperate forests (42%), followed by moist temperate (26%) and subtropical pine forest (25%).

Similarly, total area of enhancement due to improvement of forest cover density (reversal of forest degradation) was estimated as 185,155 ha with the highest improvement in Dry Temperate Forest (68%) followed by Subtropical Broad Leaved (Scrub) Forest (18%). The net balance is degradation of 157,814 ha.

The total area of forest enhancement due to reforestation and afforestation in KP during 2016-2020 was estimated as 36,487 ha. The average annual enhancement rate was calculated as 9,122 ha for the period. The highest enhancement was found in Dry Temperate Forest (17,382ha) followed by Sub-tropical Broadleaved Forest (5,255 ha) and subtropical Chir Pine Forest (4,374 ha), Sub-tropical Moist Temperate Forest (4,287 ha).

The total emissions from deforestation were estimated as 1.21 million tons of CO_2e between 2016 and 2020. The largest share of CO_2 emissions came from Dry Temperate (50%), followed by Subtropical Chir Pine (24%), Moist Temperate (17%) and Subalpine Forest (6%).

Total emissions from forest degradation were estimated as 31.74 million tons CO_2e during 2016-2020 and the total removals from enhancement due to improvement in of forest cover density was estimated as 20.97 million tons CO_2e during this period. Thus, the net balance is emission of 10.8 million tons of CO_2e.

The total removal from enhancement due to reforestation and afforestation was estimated as 5.72 million tons of CO_2e for the normal age of forests. However, for the four-year period (2016 to 2020) the total removals from enhancement came to be 0.358 million tons of CO2e, with 43% removals originating from Dry Temperate Forests, 18 % Moist Temperate Forest and 14% from Sub-Tropical Chir Pine Forests.

Overall, a net balance of 11.64 million tons of CO_2e were emitted from deforestation, and forest degradation during 2016 to 2020 in Khyber Pakhtunkhwa.

1. INTRODUCTION

1.1. Brief introduction of Khyber Pakhtunkhwa Province (KP)

The province of Khyber Pakhtunkhwa is situated between Latitude 34.0000° North and Longitude, 71.3200° East with a total area of 101,741 km². According to the 2017 census the total population of the province is 30.52 million. The province is bordered by Afghanistan in the North-West, by Gilgit Baltistan in the North-East, by Azad Jammu and Kashmir in the East, by Punjab in the South-East and by Balochistan in the South. Admiratively the Khyber Pakhtunkhwa is divided in to 34 districts including the previous 27 districts and seven newly merged districts (ex FATA). From geographic point of view the province consists of mountain ranges, undulating submontane areas, and plains surrounded by hills stretching from north to south and dividing the province in to two geographic zones i.e., the northern zone and southern zone. The northern zone starts from the Hindukush range to the Peshawar basin having cold winters with snow in the mountains to pleasant summers. The southern zone extends from Peshawar basin to the Derajat basin. It has hot summers and cold and pleasant winters. Average annual temperature of the province is 22.3 °C and average annual precipitation ranges from 406 mm to 817 mm (GoKP, 2020). Khyber Pakhtunkhwa province has six major forest types; Sub-Alpine, Dry Temperate, Moist Temperate, Sub-Tropical Chir Pine, Sub-Tropical Broadleaved (Scrub) and Tropical Thorn forests.

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 Sub-National 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, which defines the 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 GHG-Inventory. Deforestation is defined as "the direct human induced conversion of forest to non-forest (UNFCCC) or the permanent reduction of the tree canopy cover below the minimum 10% threshold" (FAO, 2015). A minimum mapping unit of 0.5 ha has been applied for the deforestation mapping (MoCC, 2020).

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

1.3.1.5. 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 KP the total calculated sample plots were 460 (92 clusters) out which 361 plots (77 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 current Sub-National GHG-Inventory Report covers the total area of the KP Province including the newly merged districts (ex FATA), which is 101,741 km^2.

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). Deforestation refers to “the direct human induced conversion of forest to non-forest (UNFCCC) or the permanent reduction of the tree canopy cover below the minimum 10% threshold (FAO, 2015) as provided in the National FREL of Pakistan (2020). On the other hand, Forest Degradation refers to “Human induced long-term losses within forest persisting of at least four years or more due to changes in canopy cover i.e., open (11-30%), sparse (31-

50%), medium (51-70%), dense (>70%) resulting in reduction in forest carbon stock and not qualifying as deforestation" (MoCC, 2021).

2.4. Consistency with National GHG Inventory

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

3. DATA, METHODOLOGY AND PROCEDURE

3.1. Mapping of Activity Data for Deforestation

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

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

Process 1: Satellite Imagery Acquisition and Processing

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

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

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

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

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

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

Process 2: Systematic Sampling Design and LULC Interpretation

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

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

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

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

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

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

Process 3: Designing Sample Set for Image Training

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

Process 4: Image Classification

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

Process 5: Post Classification Processing

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

Process 6: Accuracy Assessment and Area Estimation

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

Process 7: Land Use Change Assessment

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

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

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

3.2. Mapping of Activity Data for Forest Degradation

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

3.3. Mapping of Activity Data for Enhancement of Carbon Stock

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

Satellite images taken on the earth's surface are analyzed to identify the spatial and temporal changes that have occurred naturally or manmade. Real-time prediction of change provides an understanding related to the land cover. Province wise Pixel based change analysis of Land use land covers of 2016 and 2020, using the machine learning algorithm Random Forest (RF) and 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, meaning that 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**

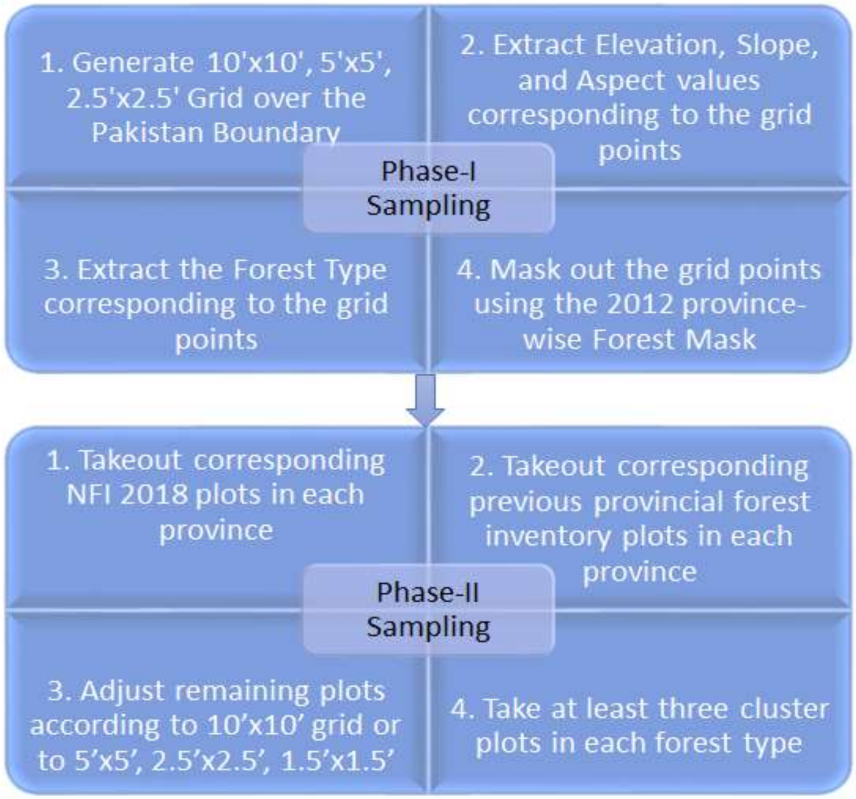


Figure 1: Stratified two-phase sampling process with integration of the SLMS process

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 2). Each sub-unit or sub-plot comprised of three concentric circular plots; 1). A plot with a radius of 17.84 meters (~1000 m^2) for measuring all living trees and standing deadwood stems with DBH1 above 5 cm; 2). A sub-plot with a radius of 5.64 meters (~100 m^2) for counting seedlings and measurement of shrubs, and; 3). A sub-plot with a radius of 0.56 meter (~1 m^2) for measuring and taking above-ground non-tree, litter and soil samples (Figure 2). Complete workflow of the forest inventory is given in Figure 3.

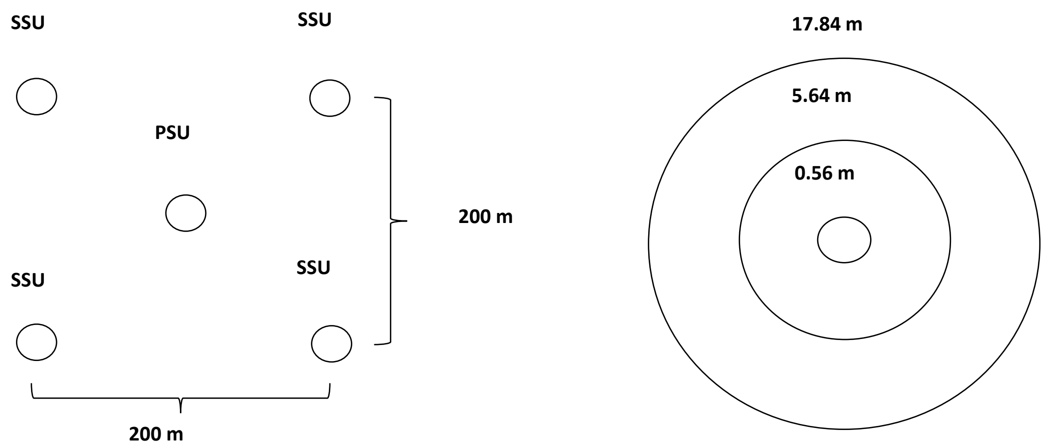


Figure 2: Clustered primary and secondary sample units (plots) (Source: NFMS-MRV Report, MoCC, 2020)

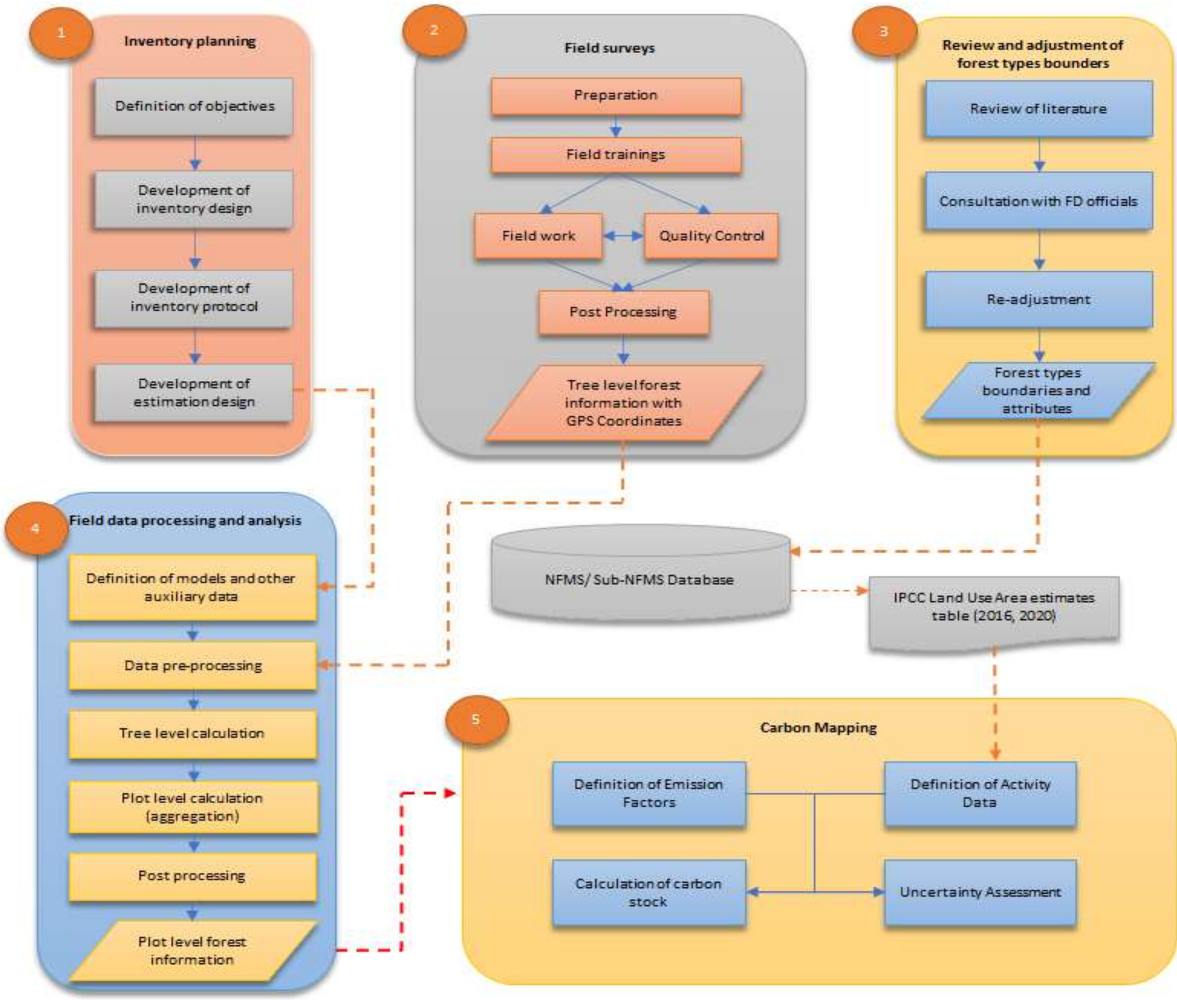


Figure 3: Forest Inventory Workflow (Source: NFMS-MRV Report, MoCC, 2020)

3.4.2. National Forest Inventory Protocol

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

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

- Cluster Information (Primary Sampling Unit)
    - Time log (starting time and reaching time)
    - Coordinates of waypoints
    - GPS coordinates of PSU location
- Plot information and Land Use
    - Measurement Time Log
    - GPS Coordinates
    - Terrain Parameters (Slope in %, Aspect, Erosion, Main site type (mineral soil, peat lands, wetlands))
    - Land Use type (forest land (and type), cropland, grassland, settlements, wetlands, other land)
    - Canopy cover (<10%, 10-30%, 31-50%, 51-70%, and >70%)
    - Disturbances
    - Land Use and Land Use Change (Deforestation, Forest Degradation and causes)
- Measurement of tally trees
    - All trees with DBH-1 above 5 cm are measured from the sample plots with radius of 17.84 m
    - 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:

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

3.4.3. Data Storage and Processing

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

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. Detailed report of data storage and processing is given as Annex-9 (provided as separate file). 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".

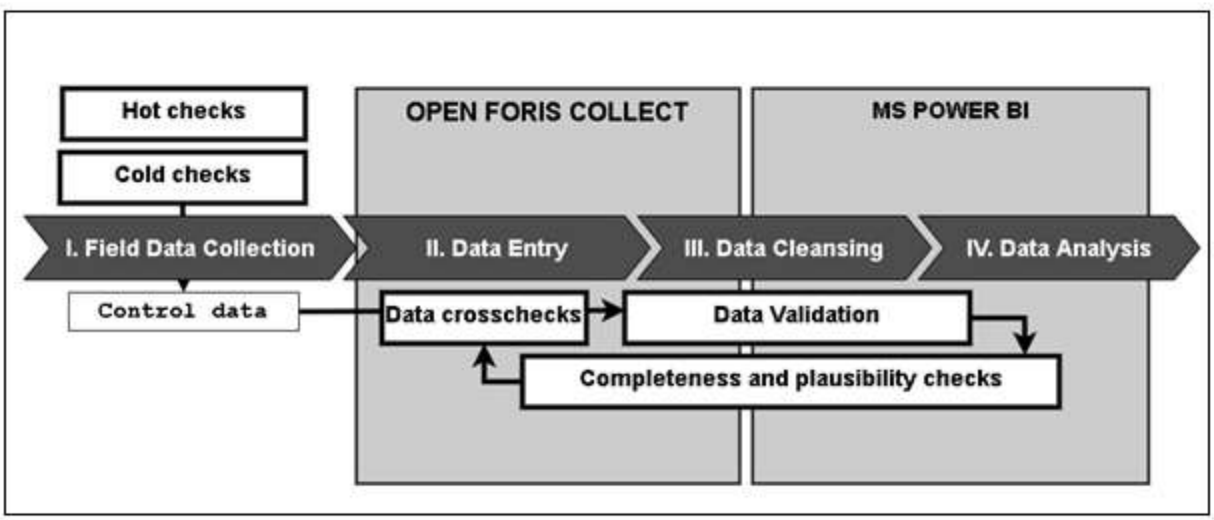


Figure 4:Data storage and processing workflow

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	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
Eucalyptus camaldulensis	5-82	2.9-48.8	279	H= -0.0051*(DBH)^2 + 0.7603*(DBH) - 0.6817 R^2 = 0.9262
Juniper spp.	5-168	1.5-10.1	190	H = -0.0002*(DBH)^2 + 0.0731*(DBH) + 2.5815 R^2 = 0.5179
Olea ferruginea	5-64	2.9-11.9	307	H = -0.001*(DBH)^2 + 0.2077*(DBH) + 2.9166 R^2 = 0.5139
Picea smithiana	5-108.2	2-41.2	149	H = -0.0035x2 + 0.6912x + 0.2213 R^2 = 0.7367
Pinus roxburghii	5-106.5	2-39.6	548	H = -0.0006*(DBH)^2 + 0.3518 *(DBH) + 5.2698 R^2 = 0.7225
Pinus wallichiana	4-134	1.5-44.5	611	H = -0.0015*(DBH)^2 + 0.504*(DBH) + 2.3565 R^2 = 0.8037
Pinus gerardiana	5-41	3.5-12.2	74	$H = 4.1531e^{0.0272(DBH)}$ R^2 = 0.5317
Quercus dilatata	5-84	1-30-3	91	$H = 0.0008x^2 + 0.2511x + 2.9845$ R^2 = 0.7541
Quercus ilex	5-51	3-21	197	H = 0.002*(DBH)^2 + 0.1873*(DBH) + 2.5811 R^2 = 0.5725
Quercus incana	5-45	2-27	241	H = 0.0099*(DBH)^2 - 0.1211 *(DBH) + 4.8764 R^2 = 0.5789
Dalbergia sissoo	5-50	2.7-30.8	70	H = 0.0038*(DBH)^2 + 0.2994*(DBH) + 3.5519 R^2 = 0.6875
Tamarix aphylla	5-50	2.9-17.2	83	H = -0.0002*(DBH)^2 + 0.3243*(DBH) + 2.6741 R^2 = 0.6423

Species	Range of DBH (cm)	Range of height (m)	Number of sample trees	Model with R^2 value
Prosopis juliflora	5-48	3.9-12.5	83	H = -0.0066x2 + 0.4956x + 1.9189 R^2 = 0.7947
Prosopis cineraria	6-46	3-16.7	46	H= -0.0043*(DBH)^2 + 0.4443*(DBH) + 1.5809 R^2 = 0.7317
Other (broadleaved) species KPK	5-54	2-19	121	H = -0.0018*(DBH)^2 + 0.3569*(DBH) + 2.4247

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

Tree Species	Model	n Tree H	RMSE	RMSE (%)
Juniperus excelsa	'-0.0002*'tree'[dbh1]^2+0.0731*'tree'[dbh1]+2.5815	353	2.008111	1.102367
Tamarix aphylla	'-0.0002*'tree'[dbh1]^2+0.3243*'tree'[dbh1]+2.6741	89	2.178909	0.67044
Pinus roxburghii	'-0.0006*'tree'[dbh1]^2 + 0.3518 *'tree'[dbh1] + 5.2698	554	4.164238	0.632527
Quercus dilatata	0.0008*'tree'[dbh1]^2 + 0.2511*'tree'[dbh1] + 2.9845	88	2.39574	0.536043
Olea ferruginea	'-0.001*'tree'[dbh1]^2 + 0.2077*'tree'[dbh1] + 2.9166	504	1.970239	0.897573
Pinus wallichiana	'-0.0015*'tree'[dbh1]^2 + 0.504*'tree'[dbh1] + 2.3565)	923	4.543665	0.55644
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
Capparis aphylla	'-0.0018*'tree'[dbh1]^2+0.3569*'tree'[dbh1]+2.4247	6	1.956157	3.766952
Diospyros lotus	'-0.0018*'tree'[dbh1]^2+0.3569*'tree'[dbh1]+2.4247	12	1.254836	1.137489
Ficus carica	'-0.0018*'tree'[dbh1]^2+0.3569*'tree'[dbh1]+2.4247	16	1.932007	0.948785
Grewia optiva	'-0.0018*'tree'[dbh1]^2+0.3569*'tree'[dbh1]+2.4247	23	2.566705	1.069688
Juglans regia	'-0.0018*'tree'[dbh1]^2+0.3569*'tree'[dbh1]+2.4247	24	2.512621	0.636264
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
Monotheca buxifolia	'-0.0018*'tree'[dbh1]^2+0.3569*'tree'[dbh1]+2.4247	31	1.44526	1.830094
Morus alba	'-0.0018*'tree'[dbh1]^2+0.3569*'tree'[dbh1]+2.4247	24	3.803151	0.8319
Prunus domestica	'-0.0018*'tree'[dbh1]^2+0.3569*'tree'[dbh1]+2.4247	6	2.41334	0.887002
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
Robinia pseudoacacia	'-0.0018*'tree'[dbh1]^2+0.3569*'tree'[dbh1]+2.4247	1	1.8358	
Syzygium cumini	'-0.0018*'tree'[dbh1]^2+0.3569*'tree'[dbh1]+2.4247	4	1.062898	0.524342
Unknown	'-0.0018*'tree'[dbh1]^2+0.3569*'tree'[dbh1]+2.4247	3	0.746974	0.398705
Quercus ilex	0.002*'tree'[dbh1]^2 + 0.1873*'tree'[dbh1] + 2.5811	418	4.959459	1.851418
Acacia nilotica	0.0023*'tree'[dbh1]^2 + 0.209 *'tree'[dbh1] + 3.6328	162	3.084328	0.796641

Dalbergia sissoo	'-0.0038*'tree'[dbh1]^2 + 0.2994*'tree'[dbh1] + 3.5519	84	5.640391	1.004632
Prosopis cineraria	'-0.0043*'tree'[dbh1]^2 + 0.4443*'tree'[dbh1] + 1.5809	130	2.518336	1.001638
Eucalyptus camaldulensis	'-0.0051*'tree'[dbh1]^2 + 0.7603*'tree'[dbh1] - 0.6817	299	3.773671	0.549415
Prosopis juliflora	'-0.0066*'tree'[dbh1]^2 + 0.4956*'tree'[dbh1] + 1.9189	164	1.174541	0.637536
Quercus incana	0.0099*'tree'[dbh1]^2-0.1211*'tree'[dbh1]+4.8764	350	5.151243	1.598699
Cedrus deodara	1.1322*'tree'[dbh1]^0.7551)	299	4.395158	0.595499
Pinus gerardiana	1.3+ 10.855563*exp(-7.885104*'tree'[dbh1]^-1)	137	3.319694	0.868547
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
Platanus orientalis	1.3+1.7688957*'tree'[dbh1]^0.5153645	1	0.283511	
Zizyphus mauritiana	1.3+1.7688957*'tree'[dbh1]^0.5153645	12	2.709529	2.788045
Picea smithiana	1.3+31.70924806*(1-exp((-0.03712483*'tree'[dbh1])))^1.46781861	189	5.211965	0.543062
Pinus wallichiana	1.3+56.25256*(exp(-19.55755*('tree'[dbh1])^-1))	923	4.543665	0.55644
Betula utilis	1.3+8.244514*exp(-7.752015*'tree'[dbh1]^-1)	15	5.34088	1.040321
Caragana ambigua	1.3+8.244514*exp(-7.752015*'tree'[dbh1]^-1)	5	1.662216	3.21085
Cordia myxa	1.3+8.244514*exp(-7.752015*'tree'[dbh1]^-1)	1	3.37207	
Phoenix dactylifera	1.3+8.244514*exp(-7.752015*'tree'[dbh1]^-1)	6	3.446182	2.360731
Populus euphratica	1.3+8.244514*exp(-7.752015*'tree'[dbh1]^-1)	4	5.097504	1.166179
Prunus dulcis	1.3+8.244514*exp(-7.752015*'tree'[dbh1]^-1)	10	1.282075	1.356375
Salix tetrasperma	1.3+8.244514*exp(-7.752015*'tree'[dbh1]^-1)	25	3.532232	0.932172
Tamarix dioca	1.3+8.244514*exp(-7.752015*'tree'[dbh1]^-1)	11	2.229631	1.400198
Zizyphus mauritiana	1.3+8.244514*exp(-7.752015*'tree'[dbh1]^-1)	12	2.709529	2.788045
Abies pindrow	2.5597*'tree'[dbh1]^0.5929)	143	6.04237	0.641715
Mallotus phillipennesis	2.6226*'tree'[dbh1]^0.4075	52	1.414962	0.683102
Acacia modesta	3.7547*LN('tree'[dbh1]) - 3.7217	178	2.056678	0.94073
Populus ciliate	'-6.9198+8.4004*LN('tree'[dbh1])	14	7.801454	2.454332
Bombax cieba	ABS(10.467*LN('tree'[dbh1])-18.124)	20	4.54334	0.611551

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 KP.

Table 8: Allometric models applied for Above Ground Biomass estimation

Sr. No	*Species Type*	Allometric Equation	Reference/ Province
1	*Populus deltoides*	M= 0.0194(D^2H)^0.9654	
2	*Abies pindrow*	M=0.0954*(DBH^2*H) ^0.8114	Ali et al. 2017 (GB)
3	*Abies pindrow*	M= 0.0495(D^2H)^0.8935	Ali 2020 (KP)
4	*Acacia nilotica*	M= 0.0493(D^2H)^0.9728	Ali 2020 (KP)
5	*Accacia nilotica*	M= 0.0569(D^2*H)^0.9745	Ali 2019 (Sindh & Punjab)
6	*Cedrus Deodara*	M=0.1779*(DBH^2*H) ^0.8103	Ali et al. 2017 (GB)
7	*Cedrus deodara*	M= 0.0458(D^2H)^0.92	Ali 2020 (KP)
8	*General (Coniferous)*	M=0.1645*(WD*DBH^2*H) ^0.8586	Ali et al. 2017 (GB)
9	*Olea ferruginea*	M= 7.8863+0.0556(D^2H)	Ali 2019 (Sindh & Punjab)
10	*Olea ferruginea*	M= 7.8863+0.0556(D^2H)	Ali 2020 (KP)
11	*Other Mix*	M=0.0673*(WD*DBH^2*H) ^0.976	RFEL/NFMS, 2020
12	*Other species*	M=Exp (-2.187+0.916*ln (WD*D^2*H))	RFEL/NFMS, 2020
13	*Picea smithiana*	M= 0.0821(D^2H)^0.8363	Ali 2020 (KP)
14	*Picea smithina*	M=0.0843*(DBH^2*H) ^0.8472	Ali et al. 2017 (GB)
15	*Pinus roxburghii*	M=0.1645*(0.327*DBH^2*H) ^0.8586	RFEL/NFMS, 2020
16	*Pinus roxburghii*	M= 0.0224(D^2H)^0.9767	Ali 2020 (KP)
17	*Populus euphratica*	Height=3.5097*LnD-1.4113	Ali 2019 (Sindh & Punjab
18	*Pinus wallichiana*	M=0.0631*(DBH^2*H) ^0.8798	Ali et al. 2017 (GB)
19	*Pinus wallichiana*	M= 0.0594(D^2*H)^0.881	Ali 2020 (KP)
20	*Quercus ilex*	M=0.8277*(DBH^2*H) ^0.6655	Ali et al. 2017 (GB)
21	*Quercus ilex*	M= 0.0795(D^2H)^ 0.9688	Ali 2020 (KP)
22	*Robinea pseudoacacia*	M= 0.2586(D^2H)^0.7786	Ali 2020 (KP)

3.5. Emission Factors for Forest Degradation

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

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

3.6. Reference Period

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

3.7. Emissions Calculation

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

- Field measurements of carbon pools and data entries;
- Height modelling for individual trees;
- Allometric biomass modelling of aboveground biomass for individual trees;
- Applying default root-shoot ratios to estimate belowground biomass;
- Laboratory analysis to determine moisture content in shrubs and litter;
- Laboratory Analysis to determine carbon contents in soil samples;
- Aggregation of plot level data;
- Expansion of plot level data to derive values on per ha basis;
- Conversion of carbon density values to CO2 equivalent

3.8. Emission Calculation from Deforestation

Deforestation refers to the conversion of forest land into another land use category. The emission factors for deforestation represent emissions per hectare of land which has been converted to non-forest land uses. 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 CO_2-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/ Other land**
Sub-Alpine Forests	2.1	3.1	0
Dry-Temperate Forests	2.1	3.1	0
Dry temperate Juniper and Chilghoza Forests	2.1	2.9	0
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

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+Dead wood+litter (ton C/ha)
	B	Forest carbon density in Sparse Moist Temperate, mean AGC+BGC+Dead wood+litter (ton C/ha)
	EF	(A-B) x 3.67
	EF	**Emission factor (ton CO2-e/ha)**

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

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

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

Enhancement	Term	Variable Definition/Formula
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)
	RF*	(A-B) x 3.67
	RF*	**Removal Factor (ton CO_2-e/ha)**
Sparse Moist Temperate Forest converted to Dense Moist Temperate Forest	A	Forest carbon density in Dense Moist Temperate Forest, mean AGC+BGC+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)**

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

4. RESULTS

4.1. Forest Type Wise Carbon Stock

The total carbon stock in KP's forests was estimated as 160.77 million tons for 2020. The average carbon density in the forests was estimated as 97.78 t/ha. The highest carbon density was found in moist temperate forest (121 t/ha), followed by dry temperate forests (102 t/ha), subtropical pine (89 t/ha), sub-alpine forest (66 t/ha), subtropical broad-leaved forests (57 t/ha) and dry tropical thorn forest (35 t/ha). The total carbon stocks for 2016 and 2020 include soil organic carbon. Total carbon stocks and carbon densities in different forest types are shown in Table 13.

Table 13: Carbon stocks in different forest types

Forest Type	2016	2020		
	Area (ha)	Area (ha)	C Density (t C/ha)	Carbon Stock (Mt C)
Sub-Alpine	15,636	19,562	66.22	1.30
Dry Temperate	812,749	838,036	101.57	85.12
Dry temperate Juniper and Chilghoza Forests	3,895	3,956	65.87	0.26
Moist Temperate	297,545	303,634	120.92	36.72
Sub-tropical Chir Pine	310,565	314,575	89.15	28.04
Subtropical broad leaved (Scrub)	157,568	162,692	57.01	9.28
Tropical Thorn	1,030	1,843	35.24	0.06
Total	**1,598,989**	**1,644,297**		**160.77**

4.2. Emission Factors for Deforestation

Emission factors for different forest types of KP are given in Table 14. Emission factors for deforestation in each forest type was derived by subtracting the mean carbon density of the respective non-forest land use from the mean carbon density of forest land use and multiplying the value with 3.67 (Table 9). Default values of mean carbon densities of the five non-forest land use classes were taken 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-11.

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

Forest Type	Mean Carbon Density (t C/ha)	SE (%)	Emission Factor (EF) (CO2e t/ha)				
			Forest-Cropland	Forest-Grassland	Forest-Wetland	Forest-Settlement	Forest-Otherland
Sub-Alpine	39.33	20.56	136.5	132.8	144.2	144.20	144.20
Dry-Temperate	52.27	11.82	184.0	180.3	191.66	191.66	191.66
Dry temperate Juniper and Chilghoza	28.65	23.02	97.4	94.4	105.06	105.06	105.06
Moist-Temperate	69.08	12.21	245.6	229.8	253.31	253.31	253.31
Subtropical Chir Pine	41.17	16.22	143.3	127.9	150.97	150.97	150.97
Subtropical broad leaved (Scrub)	10.06	15.26	30.3	21.9	36.88	36.88	36.88
Tropical Thorn	7.45	25.74	20.7	12.3	27.32	27.32	27.32

4.3. Estimates of Deforestation

The total area of deforestation in KP during 2016-2020 was determined as 7,832 ha. The average annual deforestation rate was calculated as 1958 ha for the period. The highest deforestation was found in dry temperate (3,254 ha) followed by subtropical pine forest (2,058 ha) and Subtropical broad leaved (Scrub) forest (1,130 ha). Deforestation estimates of different forest types are given in Table 15. The land use and land use change maps of KP for 2016 and 2020 are given in Annex-3, 4, 5 and 6.

Table 15: Estimates of deforestation in different forest types

Forest type	Forest-Cropland (ha)	Forest-Grassland (ha)	Forest-wetland (ha)	Forest-Settlement (ha)	Forest-Other land (ha)	Total deforestation (ha)	%
Sub-Alpine Forests	0	11	1	0	510	522	6.67
Dry-Temperate Forests	620	689	23	1	1,921	3,254	41.55
Dry temperate Juniper and Chilghoza Forests	0	4	6	0	16	25	0.32
Moist-Temperate Forests	461	146	2	0	227	835	10.66
Subtropical Chir Pine Forests	1,107	608	9	26	308	2,058	26.28
Subtropical broad leaved (Scrub)	238	629	13	1	250	1,130	14.43
Tropical Thorn Forests	5	2	0	0	0	7	0.09
Total	**2,430**	**2,089**	**53**	**28**	**3,231**	**7,832**	**100.00**

4.4. Estimates of Forest Degradation and Enhancement of Forest Cover Density

The total area under forest degradation in KP during 2016-2020 was estimated as 342,969 ha. The highest degradation was found in dry temperate forests (42%), followed by moist temperate (26%) and subtropical pine forest (25%) (Table 16). Forest type and canopy cover class wise degradation are given in Annex-11.

Similarly, total area of enhancement due to improvement of forest cover density (reversal of forest degradation) was estimated as 185,155 ha with the highest improvement in Dry Temperate Forest (68%) followed by Subtropical broad leaved (Scrub) Forest (18%). The net balance is degradation of 157,814 ha (Table 16). Forest type and canopy cover class wise enhancement in forest cover densities are given in Annex-12.

Table 16: Estimates of Forest Degradation and Enhancement in forest cover density

Forest Type	Total Forest Degradation		Total enhancement in forest cover density		Net Degradation/ Enhancement
	Area (ha)	%	Area (ha)	%	Area (ha)
Sub-Alpine	2,471	0.72	1,939	1.05	532
Dry Temperate	145,740	42.49	125,224	67.63	20,516
Dry temperate Juniper and Chilghoza Forests	137	0.04	846	0.46	-709
Moist Temperate	90,850	26.49	8,802	4.75	82,048
Sub-tropical Pine	86,187	25.13	15,035	8.12	71,151
Subtropical broad leaved (Scrub)	17,562	5.12	32,702	17.66	-15,140
Tropical Thorn	22	0.01	607	0.33	-585
Total	**342,969**	**100.00**	**185,155**	**100.00**	**157,814**

4.5. Estimates of Enhancement

The total area of forest enhancement due to reforestation and afforestation in KP during 2016-2020 was estimated as 36,487 ha. The average annual enhancement rate was calculated as 9,122 ha for the period. The highest enhancement was found in Dry Temperate Forest (17,382ha) followed by Sub-tropical Broadleaved (Scrub) Forest (5,255 ha) and Subtropical Chir Pine Forest (4,374 ha), Sub-Alpine Forest (4,335 ha) and Sub-tropical Moist Temperate Forest (4,287 ha). Enhancement estimates of different forest types are given in Table 17.

Table 17: Estimates of Enhancements

Forest type	Cropland-Forest	Grassland-Forest	Wetland-Forest	Settlement-Forest	Otherland-Forest	Total	%
Sub-Alpine Forests	2	192	0	0	4,140	4,335	11.88
Dry-Temperate Forests	226	3,848	3	4	13,302	17,382	47.64
Dry temperate Juniper and Chilghoza Forests	0	1	0	0	15	16	0.04
Moist-Temperate Forests	202	2,367	0	1	1,717	4,287	11.75
Subtropical Chir Pine Forests	795	2,203	0	26	1,349	4,374	11.99
Subtropical broad leaved (Scrub)	1,057	1,901	38	5	2,255	5,255	14.40
Tropical Thorn Forests	210	69	64	0	495	838	2.30
Total	**2,492**	**10,580**	**104**	**36**	**23,275**	**36,487**	**100.00**

4.6. Emissions from Deforestation

The total emissions from deforestation were estimated as 1.21 million tons of CO_2e between 2016 and 2020. The largest share of CO_2 emissions originates from Dry Temperate (50%), followed by Subtropical Chir Pine (24%), Moist Temperate (17%) and Subalpine Forest (6%) as shown in Table 18 and Figure 5.

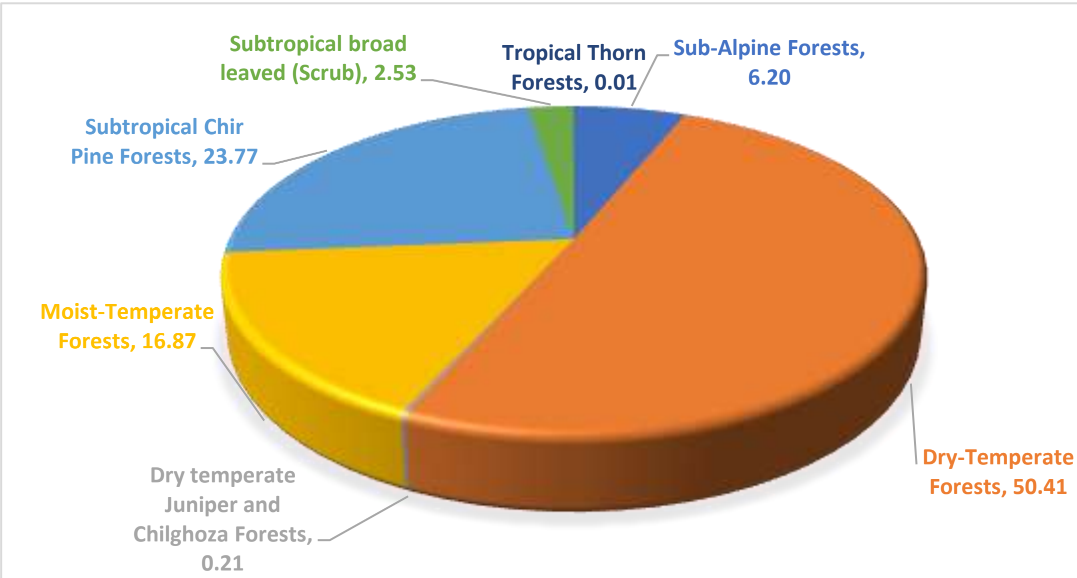


Figure 5: Distribution of Emissions from Deforestation

Table 18: Emissions from Deforestation

Forest type	Forest-Cropland			Forest-Grassland			Forest-wetland			Forest-Settlement			Forest-Other land			Total Defor. (ha)	Total Emiss. (Mt CO2e)
	Defor. (ha)	EF (CO2e t/ha)	Emiss. (Mt CO2e)	Defor. (ha)	EF (CO2e t/ha)	Emiss. (Mt CO2e)	Defor. (ha)	EF (CO2e t/ha)	Emiss. (Mt CO2e)	Defor. (ha)	EF (CO2e t/ha)	Emiss. (Mt CO2e)	Defor. (ha)	EF (CO2e t/ha)	Emiss. (Mt CO2e)		
Sub-Alpine	0	136.5	0.0000	11	132.8	0.002	1	144.2	0.000	0	144.2	0.000	510	144.2	0.074	522.45	0.075
Dry Temperate	620	184.0	0.1140	689	180.3	0.124	23	191.7	0.004	1	191.7	0.000	1,921	191.7	0.368	3254.31	0.611
Dry temperate Juniper and Chilghoza	0	97.4	0.0000	4	94.4	0.000	6	105.1	0.001	0	105.1	0.000	16	105.1	0.002	24.93	0.003
Moist Temperate	461	245.6	0.1131	146	229.8	0.034	2	253.3	0.000	0	253.3	0.000	227	253.3	0.057	835.02	0.205
Sub-tropical Pine	1,107	143.3	0.1586	608	127.9	0.078	9	151.0	0.001	26	151.0	0.004	308	151.0	0.046	2058.12	0.288
Subtropical broad leaved (Scrub)	238	30.3	0.0072	629	21.9	0.014	13	36.9	0.000	1	36.9	0.000	250	36.9	0.009	1130.31	0.031
Tropical Thorn	5	20.7	0.0001	2	12.3	0.000	0	27.3	0.000	0	27.3	0.000	0	27.3	0.000	7.02	0.000
Total	**2,430**		**0.3930**	**2,089**		**0.251**	**53**		**0.007**	**28**		**0.004**	**3,231**		**0.556**	**7832.16**	**1.212**

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 19. Uncertainties of Emission Factors of Forest Degradation are given as Annex-13.

Table 19: Emission factors for forest degradation

Forest Type	Dense - Medium		Dense - Sparse		Dense - Open		Medium - Sparse		Medium - Open		Sparse - Open	
	Δ C (t/ha)	ΔCO2e (t/ha)	ΔC (t/ha)	Δ CO2e (t/ha)	Δ C (t/ha)	ΔCO2e (t/ha)	Δ C (t/ha)	ΔCO2e (t/ha)	ΔC (t/ha)	ΔCO2e (t/ha)	ΔC (t/ha)	ΔCO2e (t/ha)
Sub-Alpine	19.80	72.60	51.22	187.82	58.12	213.09	31.42	115.22	38.32	140.49	6.89	25.27
Dry Temperate	29.39	107.77	57.31	210.15	87.58	321.13	27.92	102.38	58.19	213.36	30.27	110.98
Dry temp Juniper and Chilghoza	27.29	100.08	38.48	141.09	49.55	181.67	11.18	41.01	22.25	81.59	11.07	40.58
Moist Temperate	51.34	188.26	73.68	270.16	92.43	338.91	22.34	81.91	41.09	150.66	18.75	68.75
Sub-tropical Pine	12.91	47.33	32.53	119.29	45.42	166.53	19.62	71.96	32.51	119.20	12.88	47.24
Subtropical broad leaved	4.46	16.37	21.18	77.65	27.52	100.91	16.71	61.28	23.06	84.54	6.34	23.26
Tropical Thorn	-	-	-	-	-	-	14.88	54.55	25.35	92.96	10.48	38.41

4.8. Emissions and removals from forest degradations and improvement in forest cover density

Total emissions from forest degradation were estimated as 31.74 million tons CO_2e during 2016-2020 and the total removals from enhancement due to improvement in canopy cover was estimated as 20.97 million tons CO_2e during this period. Thus, the net balance is emission of 10.8 million tons of CO_2e. The details of forest type wise degradation and enhancement are given in Table 20. Detailed forest type and canopy cover class wise emissions from forest degradation and removals from enhancement in forest cover density are given as Annex-11 and 12.

Table 20: Emissions from Forest Degradation

Forest Type	Total degradation (ha)	Emissions (Mt CO2e)	Total improvement in forest cover density (ha)	Removals (Mt CO2e)	Net Emissions/ Removals (Mt CO2e)
Sub-Alpine	2,471	0.2	1,938.7	0.221	-0.056
Dry Temperate	145,740	15.9	125,224.3	17.339	-1.394
Dry temp Juniper and Chilghoza	137	0.0	845.9	0.051	-0.043
Moist Temperate	90,850	9.9	8,801.9	1.612	8.298
Sub-tropical Pine	86,187	5.1	15,035.4	0.785	4.284
Subtropical broad leaved (Scrub)	17,562	0.6	32,702.0	0.942	-0.301
Tropical Thorn*	22	0.0	606.7	0.0	-0.007

Total	**342,969**	**31.74**	**185,154.8**	**20.957**	**10.8**

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

4.9. Removals from Enhancement

Under the present study removals were estimated both for the normal age of forests and the reporting period of four years (2016-2020). The total removals from enhancement due to reforestation and afforestation were estimated as 5.72 million tons of CO_2e for the normal age of the forests. The largest share of CO_2 removal originated from Dry Temperate (57%), followed by Subtropical Moist Temperate Forests (17%) and subtropical Chir Pine and Sub-Alpine Forests (11% each) (Table 21).

For the four-year period (2016 to 2020) the total removals from enhancement were assessed as 0.358 million tons of CO2e, with 43% removals originating from Dry Temperate Forests, 18 % Moist Temperate Forest and 14% from Sub-Tropical Chir Pine Forests (Table 21).

4.10. Overall picture of emissions and removals

Keeping in view the overall situation, a net balance of 11.64 million tons of CO_2e were emitted from deforestation, and forest degradation during 2016 to 2020 in Khyber Pakhtunkhwa. The overall picture of emissions and removals from deforestation, forest degradation and enhancement is given in Table 22 below.

Table 21: Removals from enhancement

Forest type	Cropland-Forest			Grassland-Forest			Wetland-Forest			Settlement-Forest			Otherland-Forest			Total Enh. (ha)	Total Rem. (Mt CO2e) (for normal age)	Total; Rem (ha) (for 4 years)	%
	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)				
Sub-Alpine	2	136.5	0.0003	192	132.8	0.0256	0	144.2	0.000	0	144.2	0.0000	4140	144.2	0.5970	4334.67	0.62	0.048	13.34
Dry Temperate	226	184.0	0.0415	3,848	180.3	0.6937	3	191.7	0.001	4	191.7	0.0008	13302	191.7	2.5495	17382.42	3.29	0.155	43.05
Dry temperate Juniper and Chilghoza	0	97.4	0.0000	1	94.4	0.0001	0	105.1	0.000	0	105.1	0.0000	15	105.1	0.0016	16.38	0.00	0.001	0.39
Moist Temperate	202	245.6	0.0496	2,367	229.8	0.5440	0	253.3	0.000	1	253.3	0.0001	1717	253.3	0.4350	4286.55	1.03	0.065	18.18
Sub-tropical Pine	795	143.3	0.1140	2,203	127.9	0.2817	0	151.0	0.000	26	151.0	0.0040	1349	151.0	0.2036	4373.89	0.60	0.050	14.00
Subtropical broad leaved (Scrub)	1,057	30.3	0.0320	1,901	21.9	0.0415	38	36.9	0.001	5	36.9	0.0002	2255	36.9	0.0832	5255.46	0.16	0.037	10.37
Tropical Thorn	210	20.7	0.0043	69	12.3	0.0008	64	27.3	0.002	0	27.3	0.0000	495	27.3	0.0135	838.08	0.02	0.002	0.67
Total	**2,492**		**0.2417**	**10580**		**1.5874**	**104.3**		**0.004**	**36**		**0.0051**	**23275**		**3.8835**	**36487.45**	**5.72**	**0.358**	**100.00**

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

Table 22: Overall CO2 emissions and removals in forestry sector of KP

Forest Type	Emissions from deforestation (Mt CO2e)	Emissions from forest degradation (Mt CO2e)	Removals from enhancement (Mt CO2e)	Removals from improvement in degradation (Mt CO2e)	Net balance (Mt CO2e)
Sub-Alpine	0.0752	0.1653	0.048	0.2208	-0.0283
Dry Temperate	0.6111	15.9450	0.155	17.3390	-0.9379
Dry temp Juniper and Chilghoza	0.0026	0.0086	0.001	0.0511	-0.0409
Moist Temperate	0.2045	9.9099	0.065	1.6116	8.4378
Sub-tropical Pine	0.2881	5.0685	0.05	0.7849	4.5218
Subtropical broad leaved (Scrub)	0.0307	0.6414	0.037	0.9419	-0.3069
Tropical Thorn	0.0001	0.0004	0.002	0.0074	-0.0088
Total	**1.2124**	**31.7391**	**0.358**	**20.9567**	**11.6368**

5. RECOMMENDATIONS FOR IMPROVEMENT

5.1. Improvement of Activity Data

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

Instead of relying only on the spectral response of the images, it is recommended to integrate spectral indices of vegetation, water, snow, soil, etc. along with the spectral reflectance. In terms of forest degradation, the combination of SMA and time series could improve the results.

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

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

5.2. Improvement of Emission Factors

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

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

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

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

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

6. REFERENCES

Ali, A., Hussain.K., Ismail.M, and Hussain.K. 2017. "Forest Carbon Inventory Of Gilgit Baltistan". Gilgit: Forest, Environment and Wildlife Department Gilgit Baltistan.

Ali, A. 2019. "Biomass And Carbon Tables Tree Species Of SFM Project Areas Of Punjab And Sindh". Peshawar: Pakistan Forest Institute.

Ali, A. 2020. "Biomass And Carbon Tables For Major Tree Species Of Khyber Pakhtunkhwa". Peshawar: Pakistan Forest Institute.

Ali, A. 2018. Carbon Stock Assessment in Riverine Forests of Sindh under Sustainable Forest Management Project. Pakistan Forest Institute, Peshawar.

Belgiu, M., & Drăguţ, L. (2016). Random forest in remote sensing: A review of applications and future directions. ISPRS journal of photogrammetry and remote sensing, 114, 24-31.

Chave, Jérôme, Maxime Réjou-Méchain, Alberto Búrquez, Emmanuel Chidumayo, Matthew S. Colgan, Welington B.C. Delitti, and Alvaro Duque et al. 2014. "Improved Allometric Models To Estimate The Aboveground Biomass Of Tropical Trees". *Global Change Biology* 20 (10): 3177-3190. doi:10.1111/gcb.12629.

Climate Law and Policy/Hagler Bailly Pakistan, 2018. Framework for Design of a Safeguard Information System in Pakistan. Government of Pakistan, Ministry of Climate Change.

Climate Law and Policy/Hagler Bailly Pakistan, 2018. Framework for Feedback Grievance Redress Mechanism in Pakistan. Government of Pakistan, Ministry of Climate Change.

Christoffersen, Lisbet. 2019. Defining Non-Carbon Benefits, Working Paper Vol. 1, Forests of the World, Aarhus & Copenhagen. Available: https://www.forestsoftheworld.org/policy-documents

FAO, 2013. National Forest Monitoring Systems: Monitoring and Measurement, Reporting and Verification (M & MRV) in the context of REDD+ Activities. Available at www.fao.org/ publications.

FAO, 2016. Map Accuracy Assessment and Area Estimation: A Practical Guide. Food and Agriculture Organization of the United Nations. Rome. No.46/E.

Forestry Planning and Monitoring Circle, Khyber Pakhtunkhwa Forest Department. 2018. "Khyber Pakhtunkhwa REDD+ Strategy". Peshawar: Khyber Pakhtunkhwa Forest Department.

"Khyber Pakhtunkhwa Official Web Portal". 2022. *Kp.Gov.Pk*. http://kp.gov.pk.

Government of Pakistan, 2013. Readiness Preparation Proposal (RPP) for Pakistan. In: Government of Pakistan Ministry of Climate Change.

Government of Pakistan, 2015. Action Plan for the Implementation of the National Forest Monitoring System of Pakistan. Ministry of Climate Change, Government of Pakistan.

Government of Pakistan, 2018. Framework For Design of a Safeguard Information System in Pakistan. Government of Pakistan, Ministry of Climate Change.

Government of Pakistan, 2018. National REDD+ Strategy and its Implementation Framework. Government of Pakistan, Ministry of Climate Change.

Government of Pakistan, 2020. National Forest Monitoring System – Measuring, Reporting and Verification-Final Report. Government of Pakistan, Ministry of Climate Change.

Government of Pakistan, 2020. National Forest Reference Emission Level for Pakistan-Final Report. Government of Pakistan, Ministry of Climate Change.

Hussain, K.; Khan, M.I.; Afrasiyab, M., 2016. Capacity Based Need Assessment: National Forest Monitoring System (NFMS) for REDD+ in Pakistan. Ministry of Climate Change/WWF Pakistan/UN-REDD.

Hussain, K.; Shah, G. Q.; Nizami, A.; Ali, J.; Werter, F. 2021. Multi-stakeholder Self-Aassessment of REDD+ Readiness in Pakistan (R-Package). Government of Pakistan, Ministry of Climate Change.

Immitzer, M., Atzberger, C., & Koukal, T. (2012). Tree species classification with random forest using very high spatial resolution 8-band WorldView-2 satellite data. Remote sensing, 4(9), 2661-2693.

Intergovernmental Panel on Climate Change, 2003. Good Practice Guidance for Land Use Land-Use Change and Forestry.

Intergovernmental Panel on Climate Change, 2003b. Definitions and Methodological Options to Inventory Emissions from Direct Human-induced Degradation of Forests and Devegetation of Other Vegetation Types.

Intergovernmental Panel on Climate Change, 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Agriculture, Forestry and Other Land Use.

Intergovernmental Panel on Climate Change,1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories.

Khan, Ishfaq Ahmad, Waseem Razzaq Khan, Anwar Ali, and Mohd Nazre. 2021. "Assessment Of Above-Ground Biomass In Pakistan Forest Ecosystem's Carbon Pool: A Review". *Forests* 12 (5): 586. doi:10.3390/f12050586.

Olofsson, P., Foody, G. M., Herold, M., Stehman, S. V.,Woodcock, C. E., & Wulder, M. A. (2014). Good practices forestimating area and assessing accuracy of land change. RemoteSensing of Environment, 148, 42–57.https://doi.org/10.1016/j.rse.2014.02.015

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

UNFCCC, 2009. Decision 4/CP.15. COP15: Report of the Conference of the Parties on its fifteenth session, held in Copenhagen from 7 to 19 December 2009. FCCC/CP/2009/11/Add.1. https://unfccc.int/resource/docs/2009/cop15/eng/11a01.pdf#page=11

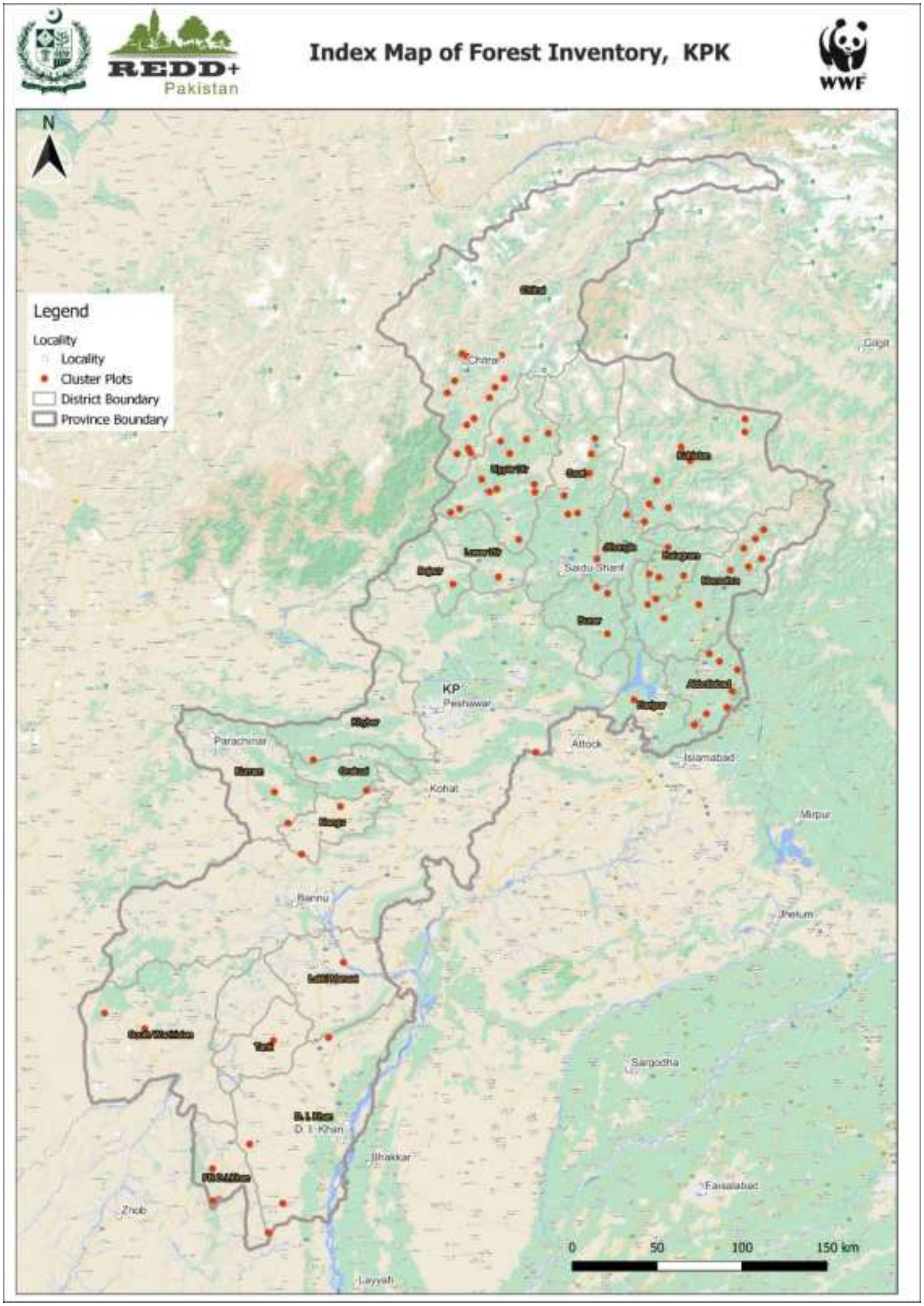
UNFCCC, 2011. Decision 1/CP.16 Paragraph 71 c. COP16: Report of the Conference of the Parties on its sixteenth session, held in Cancun from 29 November to 10 December 2010. FCCC/CP/2010/7/Add.1. https://unfccc.int/resource/docs/2010/cop16/eng/07a01.pdf#page=12

UNFCCC, 2014. Decision 11/CP.19. COP19: Report of the Conference of the Parties on its nineteenth session, held in Warsaw from 11 to 23 November 2013. FCCC/CP/2013/10/Add.1. https://unfccc.int/resource/docs/2013/cop19/eng/10a01.pdf#page=31

USGS, 2021. Landsat Processing Details | Landsat Missions. https://landsat.usgs.gov/landsat-processing-details. Accessed 19 September 2021.

7. ANNEXES

Annex 1. Forest Inventory Plots Location Map (Khyber Pakhtunkhwa)



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

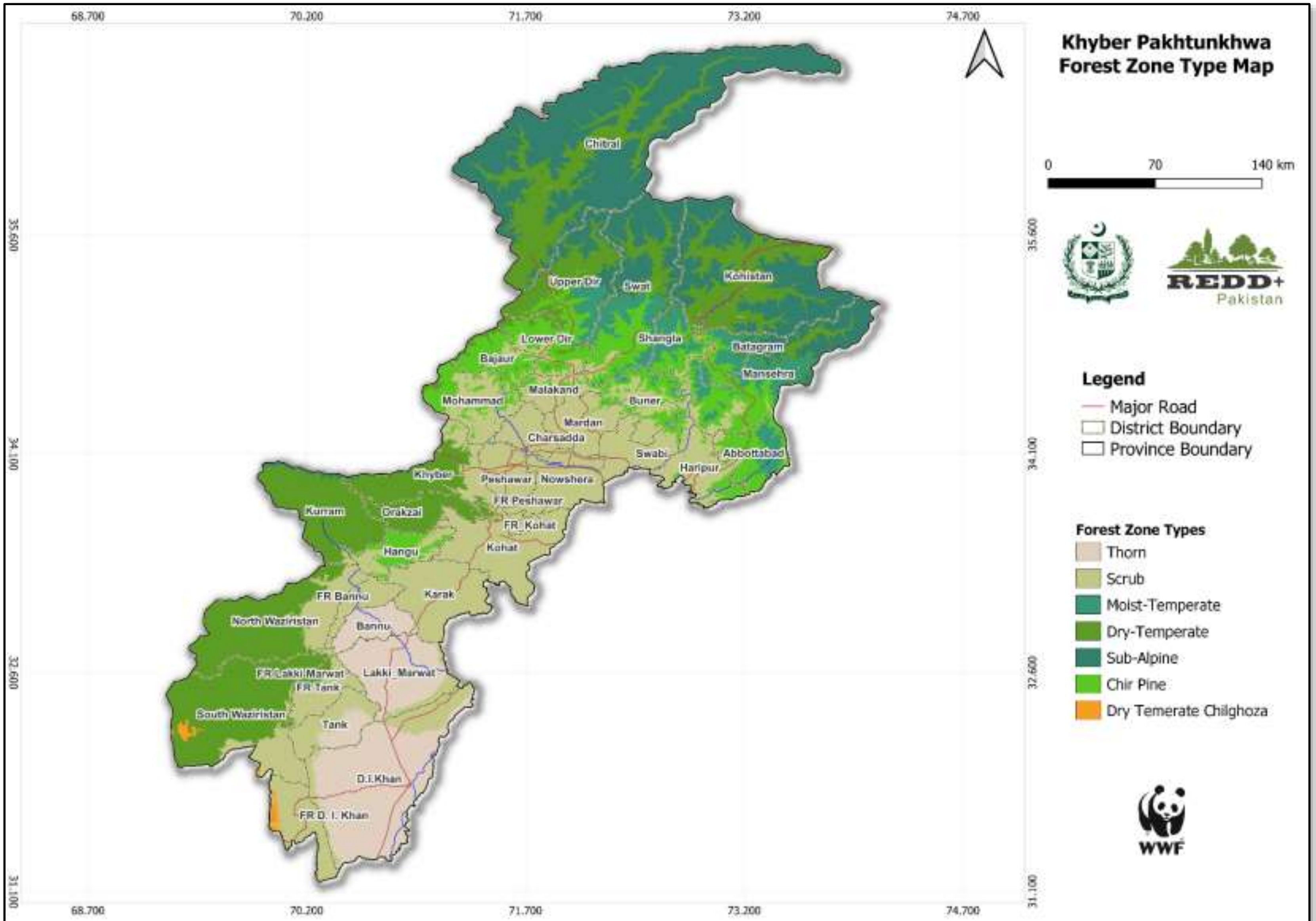
Cluster No	Cluster ID	Cluster Plot	Latitude	Longitude	UTM-Projection	Elevation	Slope	Aspect
202	KPKChP202	KPKChP202-5	3764450	891951.7	EPSG: 32642	1061	29.67856	158.0394
203	KPKMT203	KPKMT203-5	3768209	904027.6	EPSG: 32642	1941	34.5196	134.4645
204	KPKMT204	KPKMT204-5	3777742	907166.9	EPSG: 32642	2543	20.67059	228.9452
205	KPKMT205	KPKMT205-5	3781889	900453.7	EPSG: 32642	1736	49.54482	11.30993
206	KPKMT206	KPKMT206-5	3790313	910298.8	EPSG: 32642	2030	16.93829	9.46232
207	KPKMT207	KPKMT207-5	3795308	899721.2	EPSG: 32642	2171	26.89319	333.2171
208	KPKChP208	KPKChP208-5	3799752	893742.5	EPSG: 32642	1568	18.59241	140.3893
224	KPKChP224	KPKChP224-5	3862488	869421.5	EPSG: 32642	1451	29.50216	3.36646
228	KPKMT228	KPKMT228-5	3855511	827484.4	EPSG: 32642	2616	22.75718	76.6075
229	KPKMT229	KPKMT229-5	3861493	832344.2	EPSG: 32642	2129	22.64542	229.4672
233	KPKMT233	KPKMT233-5	3881686	844946.5	EPSG: 32642	2124	25.83714	318.0128
244	KPKMT244	KPKMT244-5	3906085	823012.5	EPSG: 32642	2132	44.37134	63.43495
246	KPKSbA246	KPKSbA246-5	3917366	824102.8	EPSG: 32642	3366	35.40684	116.222
247	KPKMT247	KPKMT247-5	3926503	826367.5	EPSG: 32642	2424	42.52241	107.4801
213	KPKMT213	KPKMT213-5	3848954	906046.1	EPSG: 32642	2484	13.92929	149.3814
214	KPKMT214	KPKMT214-5	3851006	916709.2	EPSG: 32642	2124	20.8825	353.1076
215	KPKMT215	KPKMT215-5	3855746	924504.8	EPSG: 32642	2365	18.72008	130.6013
216	KPKMT216	KPKMT216-5	3861799	913990.5	EPSG: 32642	2690	38.74576	297.4744
217	KPKMT217	KPKMT217-5	3872803	925719.9	EPSG: 32642	2521	8.75631	315
218	KPKMT218	KPKMT218-5	3867331	920856.2	EPSG: 32642	2398	27.77685	320.5055
285	KPKDT285	KPKDT285-5	3737303	660469	EPSG: 32642	2286	23.06878	90.65855
251	KPKMT251	KPKMT251-5	3840790	742732.7	EPSG: 32642	1699	13.98387	0
221	KPKMT221	KPKMT221-5	3845741	878566	EPSG: 32642	1695	26.58159	34.24903
222	KPKChP222	KPKChP222-5	3844712	864046.3	EPSG: 32642	1374	31.325	27.47443

Cluster No	Cluster ID	Cluster Plot	Latitude	Longitude	UTM-Projection	Elevation	Slope	Aspect
223	KPKMT223	KPKMT223-5	3846698	858358.8	EPSG: 32642	2316	26.62207	32.16439
292	KPKDT292	KPKDT292-5	3588206	537554	EPSG: 32642	2405	1.86454	203.1986
283	KPKDT283	KPKDT283-5	3700088	645593	EPSG: 32642	1042	28.2238	28.42599
284	KPKMT284	KPKMT284-5	3718460	637579.8	EPSG: 32642	1824	38.96775	58.80752
225	KPKChP225	KPKChP225-5	3835303	833769.5	EPSG: 32642	1067	24.97521	356.9335
230	KPKMT230	KPKMT230-5	3861537	845441	EPSG: 32642	2302	28.62974	140.3145
210	KPKChP210	KPKChP210-5	3811524	833687.3	EPSG: 32642	919	13.12233	340.9065
266	KPKDT266	KPKDT266-5	3918024	753060.7	EPSG: 32642	2416	45.23302	258.5815
267	KPKDT267	KPKDT267-5	3920667	751755.3	EPSG: 32642	2024	29.90463	200.3084
268	KPKDT268	KPKDT268-5	3917525	745144	EPSG: 32642	1552	39.7239	233.6428
269	KPKDT269	KPKDT269-5	3934449	750868.6	EPSG: 32642	1308	17.86616	298.0725
270	KPKDT270	KPKDT270-5	3938219	755129.7	EPSG: 32642	1710	10.4509	318.9452
271	KPKDT271	KPKDT271-5	3950440	764199.7	EPSG: 32642	1744	28.53344	113.8602
272	KPKDT272	KPKDT272-5	3956546	767540.2	EPSG: 32642	2016	12.0827	198.435
273	KPKDT273	KPKDT273-5	3961662	772913.6	EPSG: 32642	2487	7.95096	140.1944
274	KPKDT274	KPKDT274-5	3975446	771267.7	EPSG: 32642	2668	12.09342	311.5318
275	KPKDT275	KPKDT275-5	3953317	739353	EPSG: 32642	2545	27.42536	171.2188
276	KPKDT276	KPKDT276-5	3960365	743713.6	EPSG: 32642	2164	45.5626	93.85064
277	KPKDT277	KPKDT277-5	3974829	751048.1	EPSG: 32642	2126	19.13292	26.56505
278	KPKDT278	KPKDT278-5	3976463	748167.1	EPSG: 32642	2950	15.07013	268.9584
287	KPKChP287	KPKChP287-5	3573906	669400.8	EPSG: 32642	946	23.62938	190.4516
226	KPKMT226	KPKMT226-5	3838859	827283.1	EPSG: 32642	2045	30.34129	30.37913
236	KPKChP236	KPKChP236-5	3913292	882330.2	EPSG: 32642	1002	41.08854	10.77145
237	KPKMT237	KPKMT237-5	3921401	877091.3	EPSG: 32642	1700	21.95326	307.5284

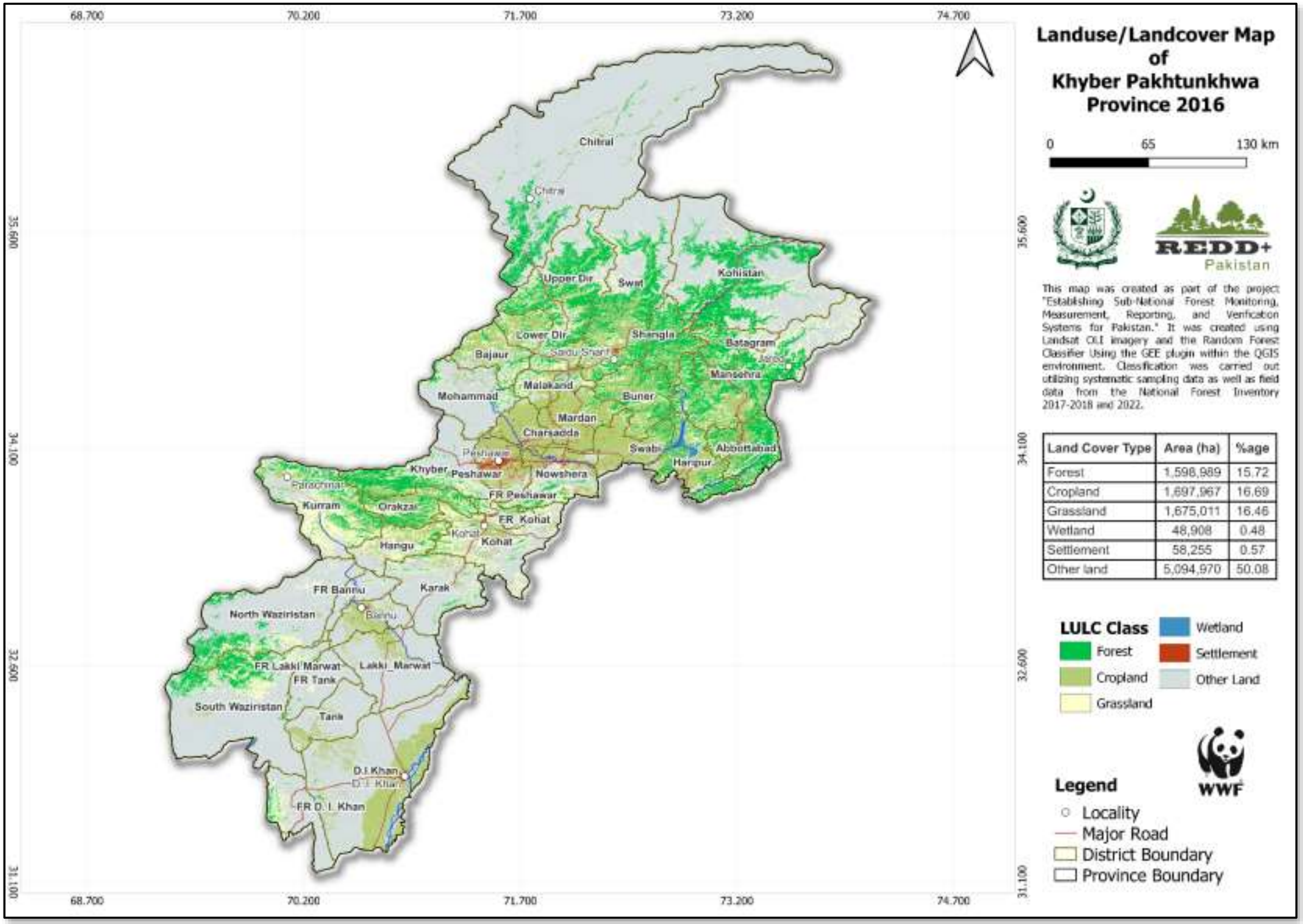
Cluster No	Cluster ID	Cluster Plot	Latitude	Longitude	UTM-Projection	Elevation	Slope	Aspect
238	KPKSbA238	KPKSbA238-5	3930358	914616.2	EPSG: 32642	3548	43.51799	96.79594
240	KPKMT240	KPKMT240-5	3938011	914592.5	EPSG: 32642	1698	7.21754	323.5308
252	KPKMT252	KPKMT252-5	3894940	790935.7	EPSG: 32642	2374	46.86157	40.23636
253	KPKMT253	KPKMT253-5	3899569	790597.7	EPSG: 32642	2172	16.59191	187.2243
254	KPKChP254	KPKChP254-5	3896750	768512.5	EPSG: 32642	1419	32.34207	143.5308
255	KPKChP255	KPKChP255-5	3895093	764298	EPSG: 32642	1342	19.52658	256.5348
256	KPKMT256	KPKMT256-5	3885114	746673.7	EPSG: 32642	1662	26.64089	291.9032
257	KPKMT257	KPKMT257-5	3882816	741346.2	EPSG: 32642	1799	18.51238	46.10171
259	KPKMT259	KPKMT259-5	3902368	759558.1	EPSG: 32642	1814	44.2887	179.2686
260	KPKMT260	KPKMT260-5	3907291	770148.1	EPSG: 32642	1843	32.23188	19.65382
261	KPKMT261	KPKMT261-5	3909115	775313.3	EPSG: 32642	2053	10.72902	343.1786
262	KPKMT262	KPKMT262-5	3917610	776152.7	EPSG: 32642	1982	35.64655	27.64598
263	KPKSbA263	KPKSbA263-5	3924857	770790.5	EPSG: 32642	3326	32.40832	64.20397
264	KPKMT264	KPKMT264-5	3926021	785889.2	EPSG: 32642	2389	18.10215	79.69515
265	KPKDT265	KPKDT265-5	3929563	798845.3	EPSG: 32642	3270	31.71714	194.9816
219	KPKMT219	KPKMT219-5	3828694	857450.2	EPSG: 32642	1832	42.39307	265.0834
288	KPKScrb288	KPKScrb288-5	3496632	601040	EPSG: 32642	1013	21.11505	345.5103
289	KPKScrb289	KPKScrb289-5	3477793	601309.5	EPSG: 32642	1185	16.43068	68.02549
209	KPKChP209	KPKChP209-5	3772627	849293.3	EPSG: 32642	926	10.06233	231.3402
281	KPKChP281	KPKChP281-5	3709851	676414.9	EPSG: 32642	1088	9.40058	29.93151
282	KPKChP282	KPKChP282-5	3681732	653632.1	EPSG: 32642	960	34.63747	38.19868
201	KPKChP201	KPKChP201-5	3757805	884921.6	EPSG: 32642	1024	36.05027	349.0772
280	KPKScrb280	KPKScrb280-5	3719388	691713	EPSG: 32642	923	35.6389	15.66816
245	KPKTh245	KPKTh245-5	3476257	642424.8	EPSG: 32642	206	0.95113	180

Cluster No	Cluster ID	Cluster Plot	Latitude	Longitude	UTM-Projection	Elevation	Slope	Aspect
258	KPKTh258	KPKTh258-5	3511016	622960.2	EPSG: 32642	242	0.36771	315
290	KPKTh290	KPKTh290-5	3459020	633895.5	EPSG: 32642	248	1.12173	270
286	KPKTh286	KPKTh286-5	3618077	678183.8	EPSG: 32642	260	1.47053	315
212	KPKChP212	KPKChP212-5	3828744	887512.3	EPSG: 32642	1491	17.89685	34.99202
241	KPKMT241	KPKMT241-5	3881926	810456.3	EPSG: 32642	1892	22.58035	15.86571
242	KPKChP242	KPKChP242-5	3882585	816086	EPSG: 32642	1253	8.67668	108.435
243	KPKMT243	KPKMT243-5	3892825	808188.7	EPSG: 32642	2016	45.23299	24.92847
279	KPKTh279	KPKTh279-5	3741662	791483.5	EPSG: 32642	364	6.10927	161.5651
211	KPKChP211	KPKChP211-5	3820608	867097	EPSG: 32642	1185	26.77644	272.7792
220	KPKMT220	KPKMT220-5	3832028	862188.9	EPSG: 32642	2411	34.23619	104.0362
232	KPKMT232	KPKMT232-5	3885723	869510.1	EPSG: 32642	2210	22.40151	218.8534
231	KPKChP231	KPKChP231-5	3877574	855599	EPSG: 32642	1230	40.91865	68.55226
234	KPKMT234	KPKMT234-5	3887947	858126.4	EPSG: 32642	2103	20.59481	330.1729
235	KPKMT235	KPKMT235-5	3901658	862692.4	EPSG: 32642	2395	44.09721	295.9355
227	KPKMT227	KPKMT227-5	3850405	833378.6	EPSG: 32642	1945	24.5649	328.2849
239	KPKTh239	KPKTh239-5	3572059	636864	EPSG: 32642	248	4.20616	273.8141
249	KPKChP249	KPKChP249-5	3859954	769132.5	EPSG: 32642	1178	6.00184	338.6294
250	KPKChP250	KPKChP250-5	3844974	769431.7	EPSG: 32642	1298	7.98565	317.6026
291	KPKMT291	KPKMT291-5	3579086	561111.2	EPSG: 32642	1688	14.35198	11.30993
248	KPKMT248	KPKMT248-5	3867013	781519.4	EPSG: 32642	1762	19.43471	93.17983

Annex-3: Forest types map of Khyber Pakhtunkhwa

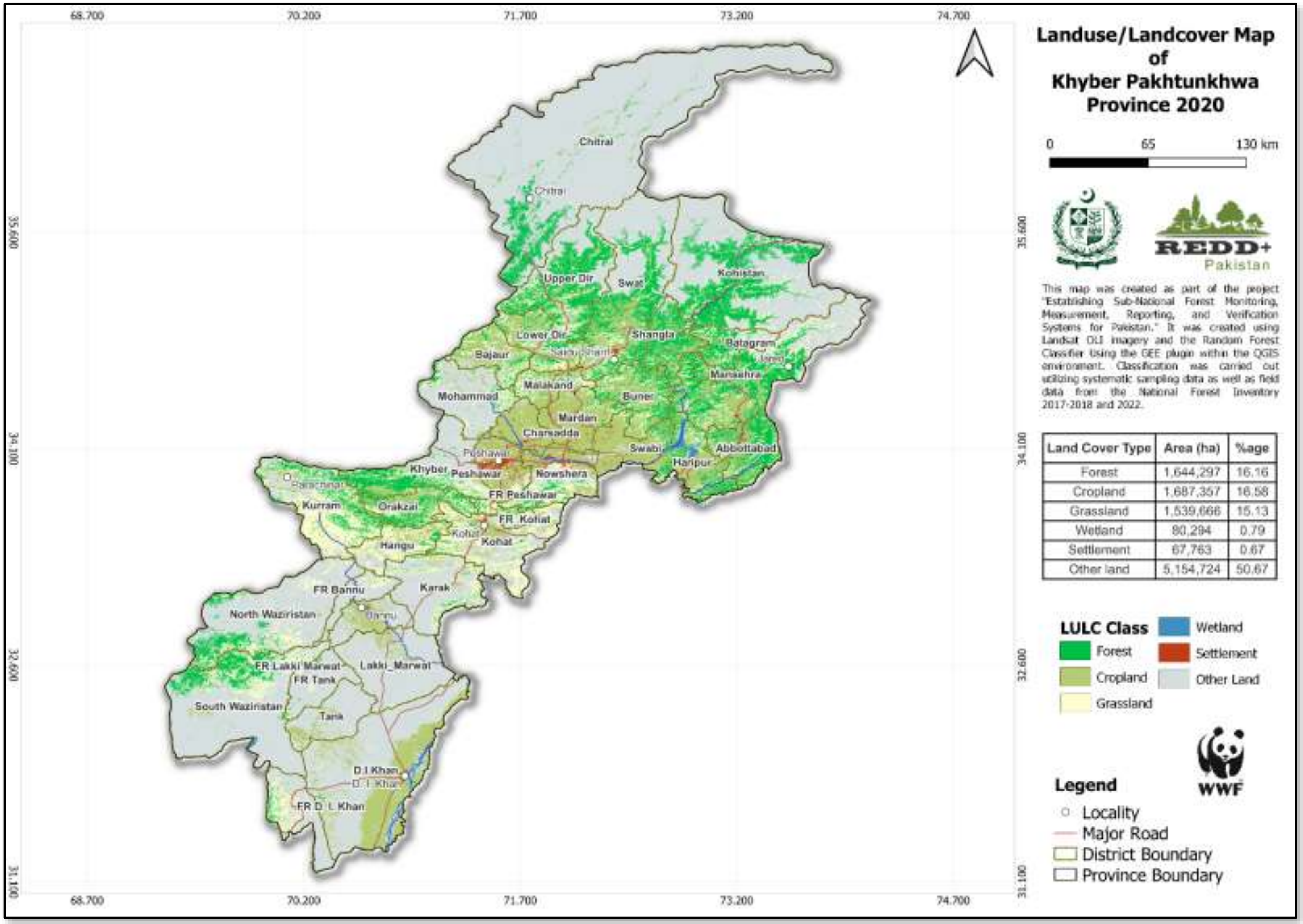


Annex-4: LULC Map 2016 of Khyber Pakhtunkhwa

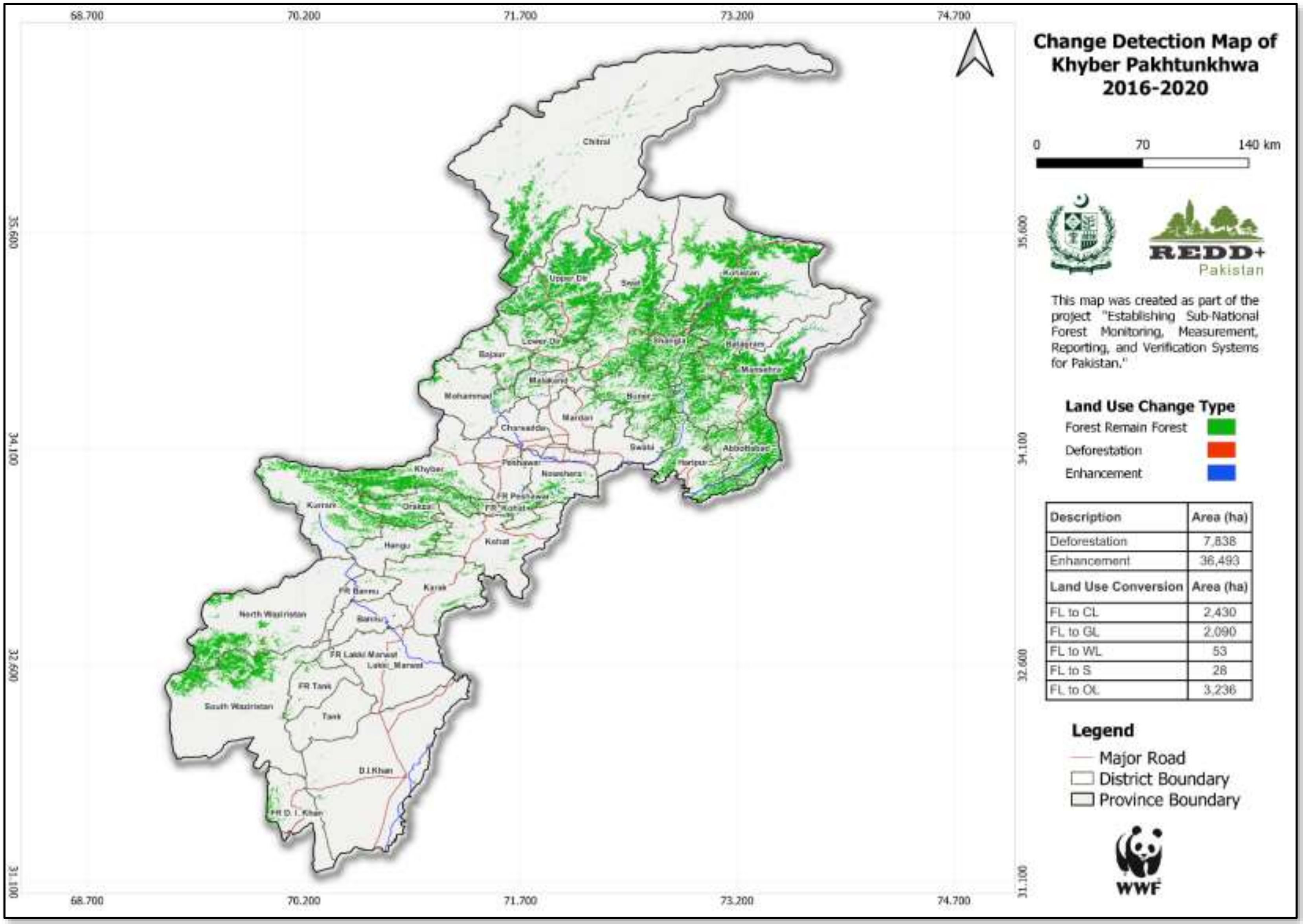


Land Cover Type	Area (ha)	%age
Forest	1,598,989	15.72
Cropland	1,697,967	16.69
Grassland	1,675,011	16.46
Wetland	48,908	0.48
Settlement	58,255	0.57
Other land	5,094,970	50.08

Annex-5: LULC Map 2020 of Khyber Pakhtunkhwa



Annex 6. Land Use Land Cover Change Map of Khyber Pakhtunkhwa



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

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

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

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

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

Forest Type	AGC (t/ha)	BGC (t/ha)	DWC (t/ha)	Litter (t/ha)	Total (t/ha) without SOC	SOC	Total (t/ha) with SOC
Sub-Alpine	31.46	7.86	0.01	0.00	**39.33**	26.89	**66.22**
Dry Temperate	41.74	10.44	0.09	0.00	**52.27**	49.30	**101.57**
Dry temperate Juniper and Chilghoza	22.87	5.72	0.06	0.00	**28.65**	37.21	**65.87**
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**

Annex-11: Details of emissions from forest degradations

Forest Type	Dense - Medium			Dense - Sparse			Dense - Open			Medium - Sparse			Medium - Open			Sparse - Open			Total	
	EF/RF CO2e (t/ha)	Deg. (ha)	Emis (Mt CO2e)	EF/RF CO2e (t/ha)	Deg. (ha)	Emis (Mt CO2e)	EF/RF CO2e (t/ha)	Deg. (ha)	Emis (Mt CO2e)	EF/RF CO2e (t/ha)	Deg. (ha)	Emis (Mt CO2e)	EF/RF CO2e (t/ha)	Deg. (ha)	Emis (Mt CO2e)	EF/RF CO2e (t/ha)	Deg. (ha)	Emis (Mt CO2e)	Deg. (ha)	Emis (Mt CO2e)
Sub-Alpine Forests	72.6	415	0.030	187.8	30	0.006	213.1	9	0.002	115.2	769	0.089	140.5	65	0.009	25.3	1,183	0.030	2,471	0.165
Dry-Temperate Forests	107.8	38,193	4.116	210.2	989	0.208	321.1	117	0.037	102.4	47,726	4.886	213.4	1,771	0.378	111.0	56,945	6.320	145,740	15.945
Dry temperate Juniper and Chilghoza Forests	100.1	50	0.005	141.1	0	0.000	181.7	0	0.000	41.0	49	0.002	81.6	0	0.000	40.6	37	0.001	137	0.009
Moist-Temperate Forests	188.3	25,135	4.732	270.2	896	0.242	338.9	29	0.010	81.9	29,616	2.426	150.7	1,003	0.151	68.7	34,171	2.349	90,850	9.910
Subtropical Chir Pine Forests	47.3	29,991	1.420	119.3	1,154	0.138	166.5	72	0.012	72.0	33,244	2.392	119.2	1,124	0.134	47.2	20,601	0.973	86,187	5.068
Subtropical broad leaved (Scrub)	16.4	5,942	0.097	77.7	254	0.020	100.9	21	0.002	61.3	6,426	0.394	84.5	229	0.019	23.3	4,689	0.109	17,562	0.641
Tropical Thorn Forests	-	9	-	-	5	-	-	1	-	54.5	7	0.000	93.0	0	0.000	38.4	0	0.000	22	0.000
Total		**99,735**	**10.400**		**3,327**	**0.613**		**249**	**0.064**		**117,837**	**10.189**		**4,193**	**0.691**		**117,627**	**9.783**	**342,969**	**31.739**

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

Forest Type	Medium-Dense			Sparse-Dense			Open-Dense			Sparse-Medium			Open-Medium			Open-Sparse			Total	
	EF/RF CO2e (t/ha)	Enh. (ha)	Rem (Mt CO2e)	EF/RF CO2e (t/ha)	Enh. (ha)	Rem (Mt CO2e)	EF/RF CO2e (t/ha)	Enh. (ha)	Rem (Mt CO2e)	EF/RF CO2e (t/ha)	Enh. (ha)	Rem (Mt CO2e)	EF/RF CO2e (t/ha)	Enh. (ha)	Rem (Mt CO2e)	EF/RF CO2e (t/ha)	Enh. (ha)	Rem (Mt CO2e)	Enh. (ha)	Rem CO2e (t/ha)
Sub-Alpine Forests	72.6	724	0.053	187.8	48	0.009	213.1	446	0.095	115.2	476	0.055	140.5	28	0.004	25.3	217	0.005	1,939	0.221
Dry-Temperate Forests	107.8	50,107	5.400	210.2	3,384	0.711	321.1	16,216	5.208	102.4	41,143	4.212	213.4	2,078	0.443	111.0	12,295	1.365	125,224	17.339
Dry temperate Juniper and Chilghoza Forests	100.1	153	0.015	141.1	13	0.002	181.7	30	0.006	41.0	333	0.014	81.6	47	0.004	40.6	269	0.011	846	0.051
Moist-Temperate Forests	188.3	6,547	1.233	270.2	64	0.017	338.9	712	0.241	81.9	1,330	0.109	150.7	15	0.002	68.7	133	0.009	8,802	1.612
Subtropical Chir Pine Forests	47.3	12,047	0.570	119.3	172	0.021	166.5	7	0.001	72.0	2,286	0.164	119.2	53	0.006	47.2	471	0.022	15,035	0.785
Subtropical broad leaved (Scrub)	16.4	23,408	0.383	77.7	719	0.056	100.9	53	0.005	61.3	7,615	0.467	84.5	160	0.014	23.3	747	0.017	32,702	0.942
Tropical Thorn Forests	-	339	-	-	116	-	-	36	-	54.5	85	0.0	93.0	28	0.0	38.4	3	0.0	607	0.007
Total		**93,325**	**7.654**		**4,517**	**0.816**		**17,501**	**5.556**		**53,268**	**5.026**		**2,410**	**0.476**		**14,136**	**1.430**	**185,155**	**20.957**

Annex-13: Uncertainties of Emission Factors of deforestation

Forest Type	Forest C Density t/ha	SE%	EF (t/ha)	SE EF (t/ha)	Sampling Error (t/ha)	95% CI	
EF deforestation (Forest to cropland)							
Sub-Alpine Forests	39.33	20.56	136.50	28.07	55.01	81.49	191.51
Dry-Temperate Forests	52.27	11.82	183.96	21.74	42.61	141.35	226.57
Dry temperate Juniper and Chilghoza Forests	28.65	23.02	97.36	22.42	43.93	53.43	141.30
Moist-Temperate Forests	69.08	12.21	245.61	29.99	58.77	186.84	304.38

Forest Type	Forest C Density t/ha	SE%	EF (t/ha)	SE EF (t/ha)	Sampling Error (t/ha)	95% CI	
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
EF deforestation (Forest to grassland)							
Sub-Alpine Forests	39.33	20.56	132.83	27.31	53.53	79.30	186.36
Dry-Temperate Forests	52.27	11.82	180.29	21.31	41.76	138.53	222.05
Dry temperate Juniper and Chilghoza Forests	28.65	23.02	94.43	21.74	42.61	51.82	137.04
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
EF deforestation overall (Forest to wetlands/ settlement/ other land)							
Sub-Alpine Forests	39.33	20.56	242.79	49.92	97.84	144.95	340.63
Dry-Temperate Forests	52.27	11.82	372.43	44.01	86.27	286.16	458.70
Dry temperate Juniper and Chilghoza Forests	28.65	23.02	241.51	55.60	108.98	132.53	350.49
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

Annex-14: Uncertainties of Emission Factors of Forest Degradation

Annex-14: (Part-a)

Forest Type	Dense - Medium							Dense - Sparse						
	ΔC (t/ha)	ΔCO_2e (t/ha)	SE%	SE ΔCO_2e (t/ha	Samp. Error (t/ha)	95% CI		ΔC (t/ha)	ΔCO_2e (t/ha)	SE%	SE ΔCO_2e (t/ha	Samp. Error (t/ha)	95% CI	
Sub-Alpine	19.80	72.60	8.80	6.39	12.52	-3.72	21.32	51.22	187.82	10.65	20.00	39.21	-28.56	49.86
Dry Temperate	29.39	107.77	17.28	18.62	36.49	-19.22	53.77	57.31	210.15	25.87	54.37	106.57	-80.70	132.44
Dry temperate Juniper and Chilghoza Forests	27.29	100.08	69.44	69.49	136.21	-66.77	205.64	38.48	141.09	66.16	93.35	182.96	-116.80	249.12
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	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Annex-14: (Part-b)

Forest Type	Dense-Open							Medium-Sparse						
	ΔC (t/ha)	ΔCO_2e (t/ha)	SE%	SE ΔCO_2e (t/ha)	Samp. Error (t/ha)	95% CI		ΔC (t/ha)	ΔCO_2e (t/ha)	SE%	SE ΔCO_2e (t/ha)	Samp. Error (t/ha)	95% CI	
Sub-Alpine	58.12	213.09	5.21	213.09	5.21	0.00	10.41	31.42	115.22	13.82	15.92	31.20	-17.38	45.01
Dry Temperate	87.58	321.13	63.77	321.13	63.77	0.00	127.55	27.92	102.38	21.35	21.86	42.85	-21.50	64.20
Dry temperate Juniper and Chilghoza Forests	49.55	181.67	68.13	181.67	68.13	0.00	136.26	11.18	41.01	29.11	11.94	23.40	5.71	52.51
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

Annex-14: (Part-c)

Forest Type	Medium-Open							Open-Sparse						
	ΔC (t/ha)	ΔCO2e (t/ha)	SE%	SE ΔCO2e (t/ha)	Samp. Error (t/ha)	95% CI		ΔC (t/ha)	ΔCO2e (t/ha)	SE%	SE ΔCO2e (t/ha)	Samp. Error (t/ha)	95% CI	
Sub-Alpine	38.32	140.49	10.22	14.36	28.15	-17.93	38.38	6.89	25.27	11.85	3.00	5.87	5.98	17.73
Dry Temperate	58.19	213.36	62.08	132.45	259.60	-197.52	321.68	30.27	110.98	65.00	72.13	141.38	-76.38	206.37
Dry temperate Juniper and Chilghoza Forests	22.25	81.59	33.34	27.20	53.32	-19.98	86.67	11.07	40.58	25.84	10.49	20.55	5.29	46.39
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

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

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

Annex-16: Mean Ages of Different Forest Types

Forest Type	Mean DBH (cm)	Mean Age (year)
Subalpine	34	52
Moist Temp	42	63
Dry Temperate	28	85
Dry Temperate Chilghoza	27	80
Subtropical Pine	28	48

Forest Type	Mean DBH (cm)	Mean Age (year)
Subtropical BL Scrub	17	17
Dry Tropical Thorn	17	34

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