Identifying potential of Reducing Emissions from Deforestation and forest Degradation (REDD) in northern Pakistan

By

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I want to dedicate this research to all people in the world working to conserve and protect forests and trying to adopt an environmental friendly lifestyle.

Sana Munawar

"How high does the sycamore grow, if you cut it down then you will never know"

"What we are doing to the forests of the world is but a mirror reflection of what we are doing to ourselves and to one another"

Chris Maser

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Abstract

Reducing emissions from deforestation and forest degradation (REDD) is a mechanism to cut down GHG emissions and protect threatened forest ecosystems. Pakistan is suffering from high deforestation rates, bringing down its forest cover from 5 to 2.5%. This study was designed to identify the potential sites for implementation of REDD/REDD+ in forest rich districts of Pakistan by using SPOT and MODIS vegetation indices. Change in the forest cover was assessed between years 2000 and 2012 in addition to the amount of atmospheric CO_2 released and/or absorbed over the study area. Results showed an increase in NDVI (Normalized Difference Vegetation Index) by 9.7 and 11.6 percent based on SPOT and MODIS observations, respectively. On the other hand CO_2 emission inventory data from EDGAR (Emission Database for Global Atmospheric Research) and REAS (Regional Emission inventory for ASia) showed an overall increasing trend which is mostly due to anthropogenic sources in the study area. Finally, CO_2 emissions calculated using carbon stock data and change in forest cover, exhibited a net sequestration of atmospheric CO_2 with huge potential of implementation of REDD+ initiative in the selected district of Dir, Pakistan.

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List of Abbreviations

IPCC	Intergovernmental Panel on Climate Change
GHG	Greenhouse gas
UNFCCC	United Nations Framework Convention on Climate Change
LULUC	Land use and land use change
LULUCF	Land use, land use change and forestry
AFOLU	Agriculture, Forestry and Other Land Use
FAO	Food and Agricultural Organization
REDD+	Reducing Emissions from Deforestation and Forest Degradation
SPOT	Satellite for observation of Earth
MODIS	Moderate Resolution Imaging Spectroradiometer
	Normalized Difference Vegetation Index
EDGAR	Emission Database for Global Atmospheric Research
REAS	Regional Emission inventory for ASia
SCIAMACHY	SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY
CDM	Clean Development Mechanism
MRV	Monitoring, reporting and verification
AD	Activity Data
GPG	Good Practice Guidelines
ARL NOAA	Air Resources Laboratory National Oceanic and Atmospheric Administration
SUPARCO	Space and Upper Atmosphere Research Commission

ETM	Enhanced Thematic Mapper
ALGAS	Asia Least-cost Greenhouse Gas Abatement Strategy
INC	Initial National Communication
LCC	Land Cover Classification
WGS	World Geodetic System
UTM	Universal Transverse Mercator
GVM	Global Vegetation Monitoring
OBI	Object Based Image
USGS	US Geological Survey
FRCGC	Frontier Research for Climate and Global Change

Chapter 1

Introduction

1.1. Background

Intergovernmental Panel on Climate Change [1], has stated that rise in earth's surface temperature has to be kept within 2° C if disastrous impacts of climate change have to be averted. It is recommended by IPCC that industrialized countries must curtail their emissions by 40 percent from 1990 levels. To reduce emissions current strategies have focused on decrease in fossil fuel consumptions, but to meet the global targets, forests and land use change have to be incorporated in climate change mitigation strategies. This demands collaborative efforts especially by taking developing countries onboard.

Forests and other vegetation types play a vital role in maintaining the balance of carbon cycle. As a result of photosynthesis forests convert the absorbed carbon dioxide from atmosphere into biomass. Therefore mature forests act as a major carbon sink by storing carbon in its above and belowground biomass. In fact forests hold more volume of carbon than the atmosphere do [2]. According to Parry et al [3] about 77 per cent of terrestrial carbon is accumulated in the earth's forest. IPCC [4] report indicates that tropical forests have 1000 tCO_2/ha worth of carbon potential.

After land clearing process such as deforestation, the carbon stored in the biomass and soil escapes back into the atmosphere adding to global GHG (greenhouse gas) emissions. Based on IPCC estimates [1] 17 per cent of global greenhouse gas emissions or 5.8 Gt of carbon dioxide equivalent (CO_2-eq) are shared by forestry sector through deforestation and forest degradation. Moreover these emissions are mainly taking place in developing countries especially in tropical rainforests.

To mitigate anthropogenic climate change, United Nations Framework Convention on Climate Change (UNFCCC) came up with a cost effective strategy in 2005 known as REDD. Initially REDD focused on providing financial benefits to developing countries to curtail their deforestation rates while protecting the rights forest-dependent communities. However conservation of carbon stock through sustainable forest management also became on the prime focus of REDD+ project (an extension of REDD). To assist developing countries in initiating REDD+ activities United Nations Program on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (UN-REDD Program) was created in 2008. This program also targeted stake holders for their capacity building to implement REDD+ mechanisms.

To make an emission reduction program effective, it is important to measure, report and verify (MRV) changes in carbon stock of a particular forested area under REDD+. MRV system focuses assessing change in forest area, carbon stock and emission factors. High-resolution satellite imagery shows changes in forest cover and land use and land use change (LULUC) patterns. Carbon stock data, derived from forest inventory, accounts for changes in carbon stock either being contributed by deforestation or degradation. The difference in carbon stock between two timespans indicates the emissions of carbon dioxide to the atmosphere [5]. The ultimate output of MRV system would be national GHG emission inventory especially from land use, land use change and forestry (LULUCF).

With a low forest cover of 2.5 percent relative to the international standard of 30 percent, Pakistan has a huge diversity of forests ranging from coastal mangroves to temperate conifer forests. This ecological set up is mainly due to arid and semi-arid climate prevalent in most part of the country. Total area covered by forest is 4.34 million hectare (Mha). Natural forests account for 4.2 Mha whereas irrigated plantations occupy 103,000 ha. Figure 1 represents the forest area occupied by Sindh, Baluchistan, Punjab, Khyber Pakhtun (KPK), Azad Kashmir and Northern Areas is 0.92, 0.33, 0.69, 1.21, 0.42, and 0.66 Mha, respectively [6]. It is evident that most of the forests are distributed is in northern parts of the country with 40 percent in KPK, 15.7 percent in Northern Areas and 6.5 percent in Azad Kashmir. The Northern region of Pakistan mainly comprises of Alpine and temperate forests. Forests in Pakistan are diminishing at a rate of 27000 Ha/year bringing it down from 5 to 2.5 percent [7].

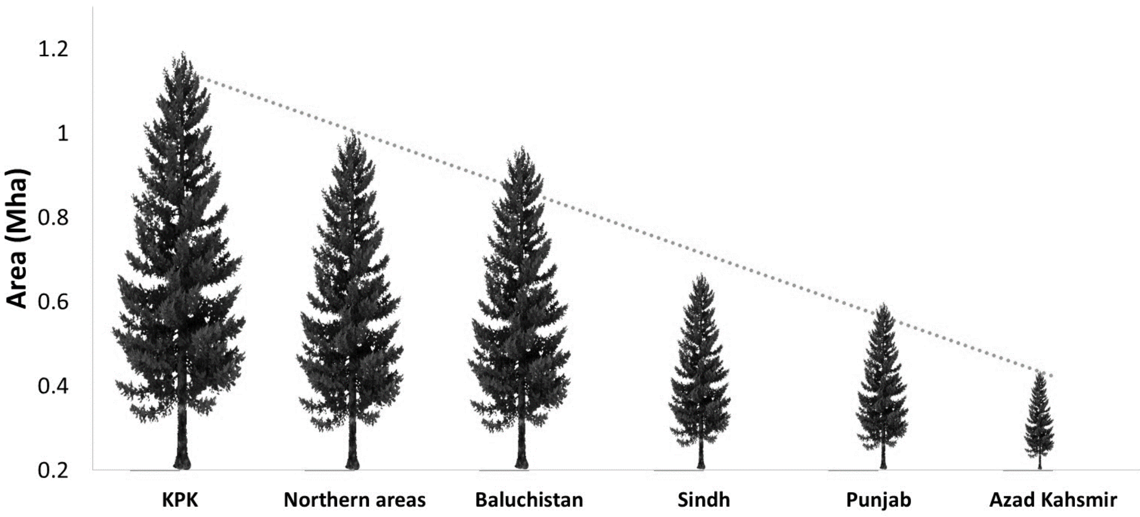


Figure 1: Distribution of forests in provinces of Pakistan

1.2. Present study

The present study identified the potential of implementing REDD+ in forest rich district: Dir of Khyber Pakhtunkhwa, Pakistan. Particular focus was laid on coniferous forests, the more abundant specie. Two important components of this study were to 1) assess change in forest cover over the study site between the years 2000 and 2012 using SPOT and MODIS and 2) to quantify CO_2 emissions released to the atmosphere from deforestation or sequestered in case of increased forest cover using CO_2 emission inventory, CO_2 satellite observations for atmospheric concentration, forest area and carbon stock data. SPOT and MODIS data was analyzed for vegetation cover through NDVI (Normalized Difference Vegetation Index) calculations. On the other hand, temporal analyses of CO_2 emission inventory data from EDGAR (Emission Database for Global Atmospheric Research) and REAS (Regional Emission inventory for ASia), CO_2 SCIAMACHY observations for atmospheric concentration over the study site was developed. Finally, CO_2 emissions were calculated using carbon stock and forest cover data and the results were compared with available emission inventories and satellite observations.

1.2.1 Study site

The study site was District of Dir located in the province of Khyber PakhtunKhua (KPK) as shown in figure 2. Total area of region of interest (RoI) is 419825 hectares (ha). Dir was selected due to availability of carbon stock data [8] for that particular region and forest type.

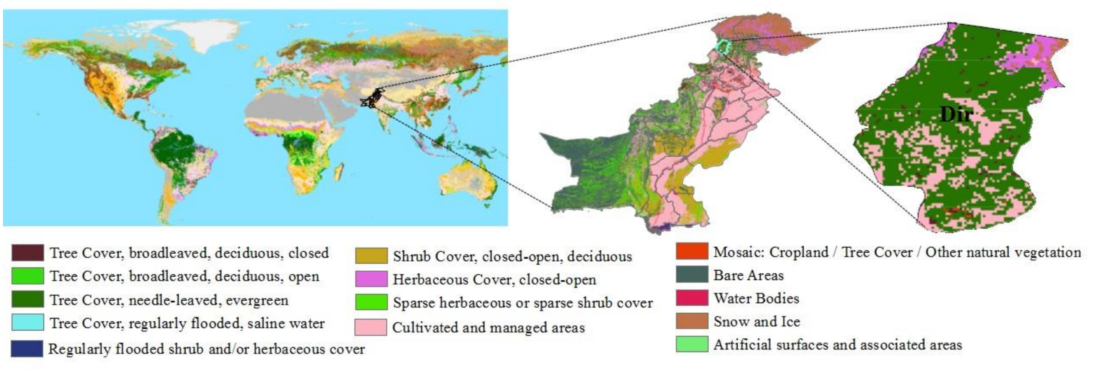


Figure 2: Study site, District Dir, KPK with an area of 419825 hectares (ha). Global and Pakistan's land cover maps obtained from Global Land Cover 2000 project developed by Global Vegetation Monitoring unit

1.2.2. Aims and objectives

- To prepare a database of forest cover (temperate conifer) of study site since year 2000
- Identify deforestation pattern over the study site
- Investigate the temporal evolution of CO_2 emissions over study site

Chapter 2

Literature review

2.1. Greenhouse effect and global warming

Energy provided by the Sun supports all existing life on this planet. Approximately half of the energy, that enters earth's atmosphere, reaches the surface, where it gets absorbed followed by is reradiated in the form of infrared (IR) radiation. GHGs absorb around 90 percent of the IR and direct it back to the surface causing it to warm up to 15^0 C, which is essential for life to survive. According to most scientists specializing in global warming, humans have enhanced the greenhouse effect causing the earth to warm up. There is a probability of more than 90 percent that anthropogenic activities for previous 250 years have warmed the earth [1].

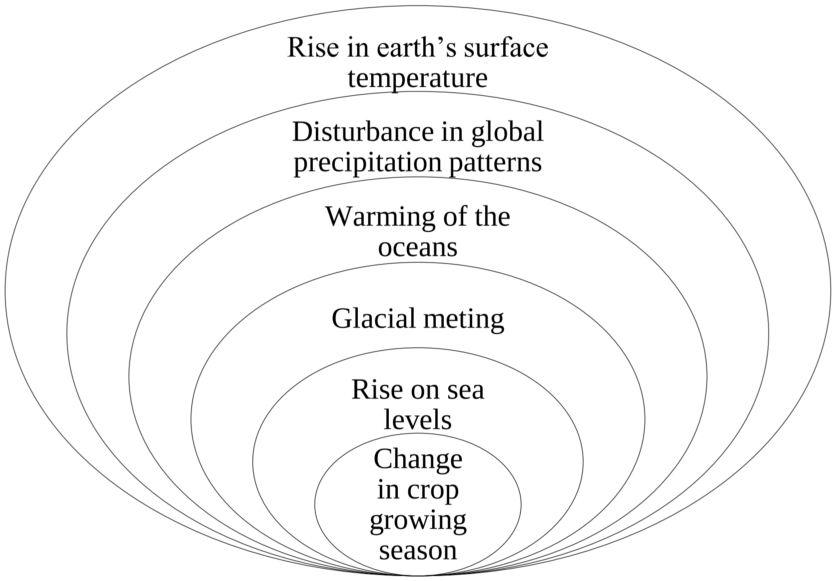


Figure 3: Consequences of global warming [9]

Human activities are significantly changing the natural greenhouse. This is mainly due to global warming pollution contributed by wide spread burning of fossil fuels, such as coal and oil. Since fossil fuels are carbon based and burning them will release CO_2 has increased the concentration of atmospheric carbon dioxide (CO_2). Other than fossil fuel burning deforestation, agricultural activities have also contributed to increased CO_2 concentration [10].

2.2. Carbon dioxide

Carbon dioxide is a trace gas, 0.04 percent of the earth's atmosphere. It consists of elements carbon and oxygen with ratio of one to two. CO_2 gas is colourless with a slight irritating odour and its mass is greater than air. Its presence in the atmosphere is imperative for our survival. When plants photosynthesize the absorb CO_2 convert it in to their biomass and as a result release oxygen [11].

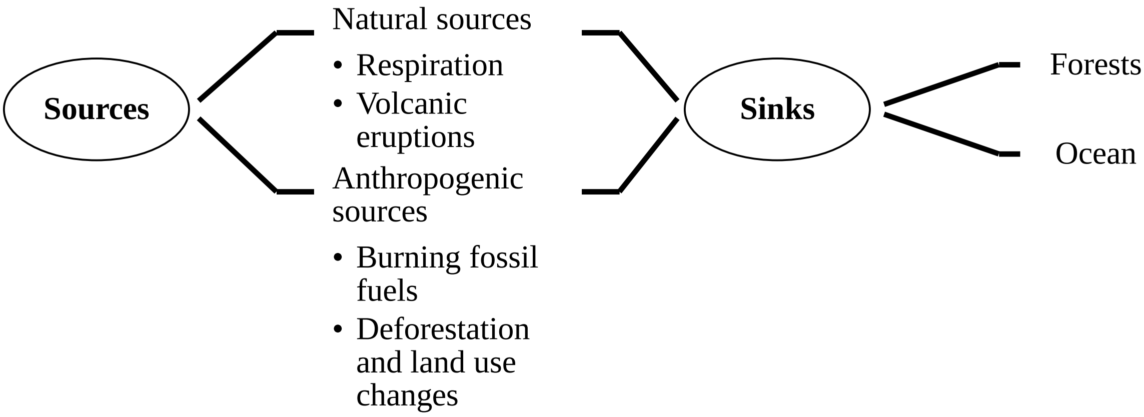


Figure 4: Sources and sink of CO_2 [12]

2.3. Climate change and REDD+

GHGs emissions have increased significantly during 19th century, causing dramatic changes in the earth's atmosphere and climate. This has led to unprecedented warming of the of our world resulting in droughts, heat waves, rise in sea levels, torrential rains, heavy floods and storms. Such climatic catastrophes will impact billions of people, in terms of food and economic security, especially small island nations, people living in coastal and arid regions.

The main contributor of global warming is carbon dioxide. Due to industrial development and extensive use of fossil fuels concentration of CO_2 in the atmosphere has expanded by 35 percent and reached up to 380 ppm [1]. Besides fossil fuel as a main contributor to CO_2 emissions, deforestation and forest degradation have a hefty share of 17 percent to the global anthropogenic GHG emissions, which is comparable to global emissions from transport sector. Therefore climate change mitigation is equally important in the forestry sector besides the energy sector.

CO_2 emissions from LULUCF, in the past two decades, have estimated to be 1.65 Gt Carbon per year [13] of which 80 percent has been contributed by developing countries, in particular tropical forest nations. Food and Agricultural Organization [14] reported a loss of 13 Mha per year of forests, along with 7.3 Mha per year haven been degraded. Developed countries struggle to curtail their emissions with the help of expensive technologies and clean development mechanisms. On the other hand developing countries are faced with the challenge to alter their economic development patterns that are less reliant on forest resources. Rising global timber demand, rights of forest communities, agriculture, and global and local food demand are some factors the governments of these countries have to deal with to protect their declining and degrading forests [15].

According to UNFCCC REDD+ is the most cost effective way to reduce GHG emissions, CO_2 in particular, by focusing on protecting existing stand of forests, conserve and enhance carbon stock and lastly secure the rights of forest dependent communities [5]. Utilizing the carbon sequestration potential of forests is favorable to developed and developing countries. Developed nations can offset their emissions through forest carbon projects, whereas developing countries can generate revenue in the form of REDD+ carbon credits and use it for the socioeconomic development.

2.4. Carbon sequestration by forests

Forests have a crucial role in global carbon cycle. They absorb CO_2 from the atmosphere and convert it in to biomass, this process is called photosynthesis. When plant respires and decompose, they stored carbon is released back to the atmosphere. Carbon sequestration by terrestrial biomass is receiving a lot of attention from the perspective of climate change mitigation. It is so because it holds huge potential in terms of containing global atmospheric CO_2. This gas is absorbed by trees, grass, below ground biomass like roots and soil as well.

Net flow of carbon in terrestrial ecosystem is the difference between amount of CO_2 absorbed and released or the difference between sink and sources. During the nineties, terrestrial biosphere, mostly forests, was absorbing carbon at a rate of 1.4 Gt per year [16] where trees and soil contain 1,146 Gt of carbon. 37 percent of this carbon is in low-latitude forests, 14 percent in mid-latitude 49 percent at high-latitudes. Carbon density (mass of carbon per unit forest area) is greatest in highlatitude forests owing to large stocks of soil carbon and is lowest in mid-latitude forests [17].

In the year 2000, 30 percent of the earth's surface was covered by forest, with half located in the tropics, one third in boreal region 10 percent lying in sub-tropical and temperate areas. Due to human intervention this proportion of forested land is being disturbed. Between 1990 to 2000 tropical forests decreased by 14.2 Mha per year mainly due to deforestation. However opposite trend is observed for forests in non-tropical regions where they have increases by 1.7 Mha per year. This increase can be attributed to natural expansion [18].

Sustainable forest management can enhance carbon sequestration potential of forests. For instance planting new trees, improved timber harvesting and regenerating forests can also result in net carbon sequestration in wood products and new forest growth.

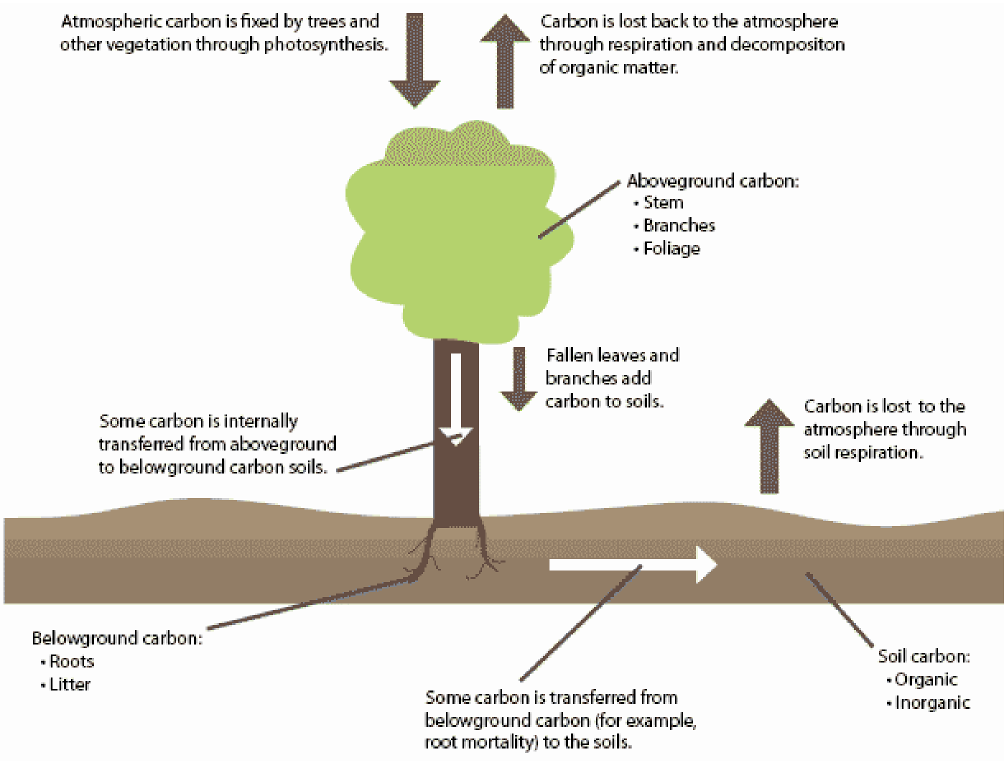


Figure 5: Carbon sequestration by forests

2.5. Forest

Forest is a land with canopy cover of more than 10 percent on an area more than 0.5 ha with tree height reaching to a minimum of 5 meters when mature [19].

2.5.1. Deforestation and Forest degradation

Deforestation is the process of forested land being converted in to some other type of land use without the possibility of regeneration. UNFCCC defines deforestation as the conversion of forest land to non-forested land as a result of direct human intervention [20]. In other words deforestation would be reduction in canopy cover below a defined threshold. This threshold limit country specific, for instance it could be 30, 20 or 10 percent. Moreover if forests temporarily fall below the threshold for example due to logging where there are chances for regeneration then this would be recorded as deforestation.

Forest degradation is a process leading towards devaluation of forest resources and services and loss of carbon stock [21]. Degradation represents tangible and human-driven decrease in carbon stocks, with the tree cover remaining above the threshold, such as conversion of forests having high carbon stocks to plantations with lower carbon stocks. Factors contributing to degradation are logging, loss of biodiversity, alien species invasion and/or poor growth of forests due other anthropogenic factors. At the moment consensus is still being made on carbon stock threshold.

2.5.2. Drivers and causes of deforestation

Deforestation is driven by variety of complex factors. Primary cause of deforestation is agriculture, followed by infrastructure and wood extraction [22]. The causes of deforestation and forests degradation are subject to change, depending on socioeconomic, socio political, governance, poor implementation of forest policies, land owner ship disputes and institutional factors. Some other deforestation drivers are [23,24]:

- Economic and industrial growth
- Population growth, increased urbanization and land encroachment
- Food consumption patterns

- Competition for croplands
- Poor agricultural practices
- Mining

2.5.3. Drivers and causes of degradation

- Conversion to plantations/ agricultural land having carbon stocks less than the forest being replaced.
- Selective logging for timber: tree felling gaps, roads, and log decks can be detected using medium resolution satellite imagery like Landsat.
- Forest fires also effect carbon stock, especially in areas where they are human induced.
- Over grazing, cutting trees for fuel wood.

2.6. REDD+ in Pakistan

Pakistan is the member of the Coalition of Rainforest Nations and also signatory to the initial REDD+ proposal submitted by the Rainforest Coalition in 2008. To develop REDD+ readiness roadmap Pakistan joined UN-REDD Program in 2011 and received Targeted Support funds for this purpose. This fund will eventually lead to development of National Forest Monitoring System. As an initiative to protect its forest resources and gain financial benefits from it Pakistan has launched nationwide unilaterally financed Mega- Carbon sequestration project which will lay a foundation to fulfill REDD+ objectives.

Pakistan has initiated its REDD+ Preparedness Phase which is a collaboration between Climate Change Division of Pakistan, International Centre for Integrated Mountain Development (ICIMOD) and WWF-Pakistan. It is financial supported by United Nation Development Program (UNDP) through One UN Joint Program on Environment (JPE). This project will go forward with the aim to develop national REDD+ strategy for Pakistan by incorporating the regional experience ICIMOD has gained through REDD+ pilot activities in Nepal and the presence of WWF-Pakistan. Khyber Pakhtunkhwa (KPK) and Gilgit Baltistan have initiated pilot activities related to REDD+.

2.7. State of forests in Pakistan

At present forests of Pakistan are suffering from large-scale deforestation and degradation. And it is continuing unprecedentedly by 0.75 per cent per year [25]. In 1992 forested land was 4.242 Mha, which declined to 3.44 million hectares in 2001. Since independence in 1947 61,000 ha of forest land have been converted to some other land use type.

The Mangrove forests, in Indus delta, have suffered highest rate of deforestation at 2.3 percent per year, followed by coniferous forests and ravine forests at 1.99 percent and 0.23 percent respectively. On provincial basis the conversion of forest land to non-forest land is highest on Punjab with conversion of 977 ha of land, Sindh with 279, Baluchistan with 137, KP with 100 ha and lastly lowest in AJK 6 ha [26].

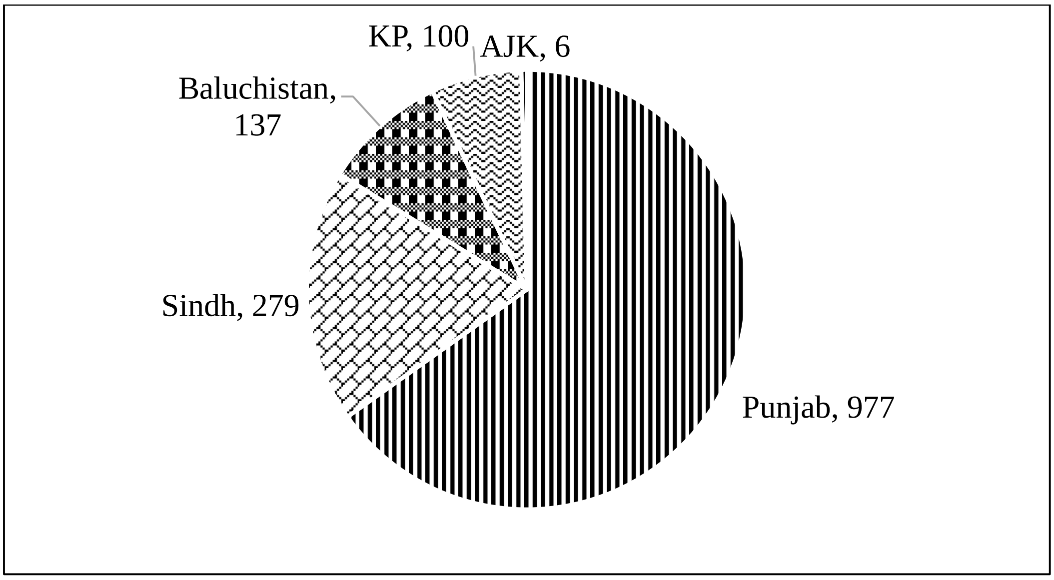


Figure 6: Conversion of forest to non-forest land (hectares) province wise [26]

On the contrary government statistics show an increase in forest cover by 21.1 percent from 1947 to 1994. This increase is mainly attributed by afforestation and agro-forestry projects and strict control in illegal logging [27].

Some studies have reported significant deforestation mainly contributed by illegal timber extraction. Former Prime Minister of Pakistan lifted the ban from timber transportation which was imposed in the early nineties. As soon as the ban was removed 2.07 million cubic of timber was transported to different parts of the country. Timber mafia also benefitted from this opportunity by chopping trees worth Rs 8 billion [28].

2.7.1. Temperate coniferous forests in Pakistan

These forests, dominant in Pakistan, mostly grow in northern parts of the country at an elevation between 1000 and 3500 meters. They are abundant in places like Mansehra, Dir, Swat, Malakand and Abbottabad districts of KPK and Rawalpindi district of the Punjab. Major species include fir, spruce, deodar, blue pine and chir pine. Coniferous forests as a whole cover 1.93 Mha or 40.92 percent of total forests in Pakistan. Provincial distribution of these forests is highest in KP with 1073000 ha, AJK with 407000 ha, Northern Areas with 285000 ha, Baluchistan with 116000 ha and Punjab with 49000 ha [29]. They play an important role in timber provision, protection of land and soil on steep mountain slopes, supply of fuel wood and non-wood products, medicinal plants, livestock grazing and as well as support the habitat of wildlife species. Some of the coniferous forests types are [30]:

Himalayan moist temperate forests

These forests, with limited undergrowth, includes evergreen and deciduous species. They grow at elevations between 1500 and 3000. Specie distribution is based on lower an duper zone these forest. In the lower zone, Cedrus deodara, Pinus wallichiana, Picea smithiana and Abies pindrow (Partal) are dominant. In the upper zone Abies pindrow and Q. semecarpifolia are the dominant tree species.

Himalayan dry temperate forests

These are open evergreen forest with open scrub undergrowth. Both coniferous and broad-leaved species are present. This type occurs on the inner ranges throughout their length and are mainly represented in the north-west. Dry zone deodar, Pinus gerardiana (Chalghoza) and/or Quercus ilex are the main species. Higher up, blue pine communities occur and in the driest inner tracts, forests of blue pine, Juniperus macropoda (Abhal, Shupa, Shur) and some Picea smithiana are found locally.

Sub-alpine forests

Evergreen conifers and mainly evergreen broad-leaved trees occur in relatively low open canopy, usually with a deciduous shrubby undergrowth of Viburnum (Guch), Salix (Willow, Bed). The type occurs throughout the Himalayas from about 3,350 m to the timber limit. Abies spectabilis and Betula utilis (Birch, Bhuj) are the typical tree species. High level blue pine may occur on landslips and as a secondary sere on burnt areas or abandoned clearings.

Alpine scrub

This category mainly includes shrub formations 1 to 2 meter high but extending up to 150 meters. These forests are characterized by Salix, Lonicera (Phut), Berberis (Sumbul, Sumblue), Cotoneaster with Juniperus and occasionally Rhododendron or Ephedra (Asmania).

2.7.3. Forest mapping in Pakistan

To assess a country's potential for REDD+, historic pattern in forest cover and related CO_2 emissions have to be quantified. This will give a trend of possible future emissions if deforestation prevails. The use of remote sensing is a suitable method because satellites record the earth's land cover over the past decades. This data is archived and can be analyzed of past changes in forest cover indicating the deforestation trends. There has to be a LULUC database in place for developing temporal and spatial records and assessing its variation over the years. In Pakistan forest cover assessment has been carried out on city or district level. Space and Upper Atmosphere Research Commission (SUPARCO) has carried out studies to assess the forest resources of Pakistan. Some of their research activities include mapping land cover of Swat, exploring the pattern of irrigated plantations in Changa Manga and mapping the Mangrove forest along the coastal areas and the Indus delta.

Siddiqui et al [31] evaluated the distribution of the Riverine forests along the river Indus plains. The results indicated 1042 ha loss of Riverine forests per year with a total loss of about 21,590 ha during the study's temporal coverage from1977 to 1998. In a similar study by Habibullah et al [32] temporal changes in Riverine forest cover of Sindh between 1979 and 2009 were identified. Land cover of study area was classified in to: forests, grassland/agricultural land, dry land/land use and water. By comparing land cover maps the annual ratio of depletion of forests came out to be 9.0%, with a total loss of 85% of forest cover from 1979 to 2009.

Assessing the decline of Coniferous forests in all provinces of Pakistan was done by Ahmad et al [33] using GIS applications. Their study, which showed an overall decrease in forests, detected forest cover change from 1992 to 2010.

A study in 2005 carried out by Ali et al [34] determined the change in forest cover in Basho valley by comparing Landsat images of 1976 and 2002. They also tried to determine the causes of forest loss with the help of surveys, workshops and interviews with forest department, forest contractors, Basho Development Organization and the local community. According to their results the major contributing factor towards deforestation is mismanagement of forest department and illegal harvesting instead of over population.

Forest cover assessment of Ayubia National park has been carried out by Abbas et al [35] using high resolution imagery of Quickbird. Their study was successful in classifying land cover of Ayubia National Park into the following classes: conifer forest, conifer forest (shadowed), mix forest grasses, build up area and bare rocks/soil. The area covered by Coniferous forest, as calculated in this particular study, came out to be 2100 ha.

Rizwan et al [36] by using GIS techniques and Landsat Enhanced Thematic Mapper (ETM) extracted the forest cover of Toba Tek Singh, district of Punjab. Comparison made between the official forest area allotted to forest departments and the actual area covered by forests showed that the actual forest area (2140 ha) is less than the allotted area (5896 ha).

Abbas et al [37] assessed the distribution of mangrove forests along Makran coast of the Baluchistan Province and the entire Indus Delta within the Sindh Province. The study used images of ALOS-AVNIR-2, with a resolution of 10 m, for the year 2009. Multi-scale Object Based Image Analysis showed that mangrove cover spread to an area of 98,128 ha in Pakistan. Land cover maps developed had the following classes: dense mangrove, medium mangrove, sparse mangrove, algae, saltbush/ grasses, mudflats and water.

2.7.4. Biomass and carbon stock measurements in Pakistan

Forest carbon assessment and forest inventorying is one of the prime requirements of implementing forest monitoring and MRV system. Pakistan lacks in complete and accurate statistics on carbon stock values, growing stocks and standing volume of its forests. The only available carbon stock data for Pakistan is that collected by of Food and Agricultural Organization (FAO) and through local research.

According to FAO [19] the total biomass of forests in Pakistan, including living and dead wood, is 573 million metric tons (Mmt). Nizami et al [38] carried out carbon stock assessment of the sub-tropical pine forests in Murree, Pakistan. In another study by Raqeeb et al [39] growing stock volume of temperate forest in Gilgit Baltistan, Pakistan was estimated. The study also tried to determine the relation between height and volume with respect to diameter of the dominant species. Kanwar and Ahmad [40] estimated carbon potential for total forests of Pakistan to be 389 mega tons.

2.8. GHG emission inventory of Pakistan

Being signatory to Kyoto protocol and UNFCCC Pakistan is obligated to submit national GHG report to UNFCCC after every two years. Pakistan's last GHG inventory, Initial National Communication (INC) developed for 1993-94, was submitted to UNFCCC in 2003. The inventory covers major sectors like energy, transport and LULUCF. In the forestry sector the CO_2 emissions reported are for changes in forest carbon stock. Total carbon uptake was estimated as 11,451Kt (kilotons)**,** while annual carbon release was 13,231 Kt. Net carbon release thus comes out to be 1780Kt, which translated into net emissions of 6527Gg (giga grams) of carbon dioxide [41].

According to the results of a GHG inventory developed by Khan et al [42] with temporal coverage from July 2007 to June 2008 the total carbon uptake was 87,284 Gg. With annual carbon release estimated as 18,730 Gg, net CO_2 up-take came out to be 68,676 Gg. Outcomes of both inventories were achieved using Revised IPCC Guidelines of 1996 for National Greenhouse Gas Inventories.

Emission inventory record maintained by EDGAR and REAS are in the form of gridded data. The gridded data can be used to generate spatial and temporal maps of GHG flux in tons. Moreover data used to develop maps holds information of total carbon dioxide emissions and emissions sector wise as well. Ample gridded data is available over Pakistan; however the mapping of carbon dioxide is still in developmental stages.

2.9. Quantifying emissions (emission factors) from LULUCF

2.9.1. Gross and net emissions

Carbon emissions contributed by deforestation and forest degradation can be estimated from gross or net changes in carbon stocks. Gross emissions assume removal of trees and any other vegetation type resulting in emission of total carbon. However net emissions take in to account the carbon sequestered by the vegetation replacing forests. As illustrated in figure 6 carbon sequestered in the replacing land use is 60 t, therefore, net emissions are 90 t (150 – 60). But if this 60 t is not considered then the gross emissions would be 150 t of carbon. This phenomena has to be kept in mind when reporting net emissions from LULUCF.

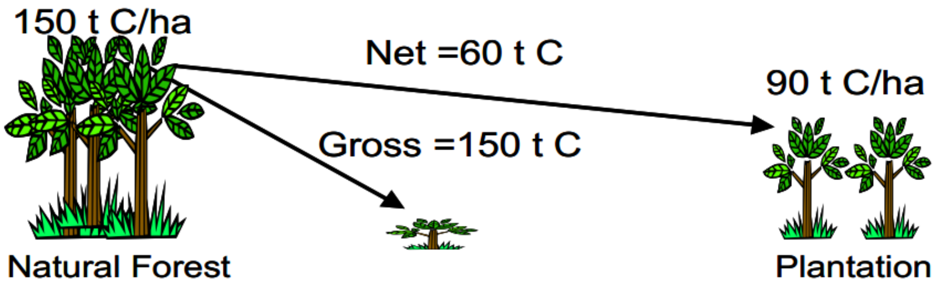


Figure 7: Gross and net emissions

2.9.2 Emission Factors

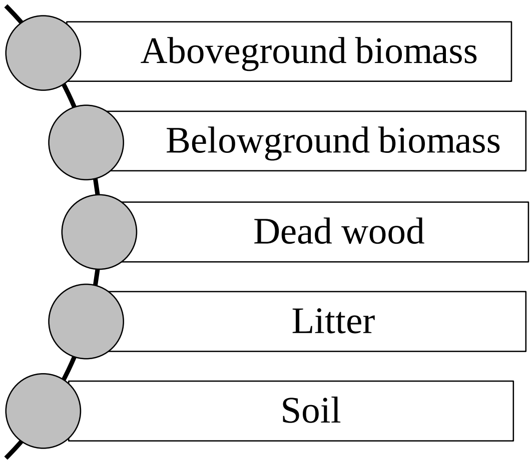
Three important aspects of Emissions Factors are [43]:

Gases

Emissions and removals various from land conversions are calculated based on the differences in initial and final carbon stocks of the land cover type. Although non CO_2 gases are also emitted but from REDD+ perspective CO_2 is considered. Moreover these emissions are reported as CO_2 tons per hectare.

Pools

Carbon pools in a forest are:



Tiers

Tiers are the assessment of Emission Factors/ changes in carbon stocks in the designated carbon pools of a forest with different levels of certainty. There are three tiers:

- Tier 1 approach does not require fresh data collection or ground based measurements for carbon stock assessment. Standard values for biomass or tree volume can be used from IPCC Agriculture, Forestry and Other Land Use (AFOLU) report. Using this approach will lead to results having low certainty with error range of about ±30-70 percent. Furthermore, Tier 1 estimates provide poor resolution of forest biomass varying at sub-national level.
- Tier 2 is an improved version of Tier 1 such that emphasizes on using data specific for that country like national reports and inventories. Another advantage of Tier 2 over Tier 1, which assumes total emission of carbon, is the accounting of carbon being transferred from woody biomass to litter. Following this approach will make Emissions Factors more reliable.
- Tier 3 approach is quite accurate as it quantifies Emission Factors based on periodic carbon stock assessments including carbon exchange between different carbon pools.

2.9.2.1. Quantifying CO_2

The IPCC AFOLU provides details on how CO_2 emissions can be estimated. There are two ways to estimating CO_2 emissions [43]:

Stock difference approach

This method is based on the difference between carbon stocks at two time spans within a particular carbon pool. This method can be applied for data derived from any Tier level. In the case of deforestation, where total loss of carbon stock is assumed and only gross emissions are considered, data for initial carbon stock is sufficient. Whereas for degradation carbon tock for both time periods has to be known as net emissions have to be calculated. Following equations are used in stock difference approach to estimate CO_2 emissions:

Deforestation—(CO_2 emissions/year) = Area deforested/year x C stock of forest

Degradation—(CO_2 emission/year) = Area degraded/year x (C stock non-degraded forest – C stock degraded forest)

Gain-loss approach

To use gain loss method for emission calculation by deforestation data derived from Tier 3 approach has to be used. Tier 1 and 2 approach would be inapplicable. On the other hand gain loss method is quite useful to calculate emissions from degradation using data derived from any level of Tier. Loss in biomass will be determined using data of timber harvest, fuel wood harvest and litter. Gain in biomass would be recorded upon forest regeneration.

2.10. Satellite forest monitoring in the context of REDD+

To keep track of REDD+ activities, remote sensing has been widely used as an observational tool [44]. Remotely sensed data, satellite and LIDAR, provides historic time series, based on which future deforestation patterns can be modelled. Besides remote sensing, ground based measurements for carbon stock assessment are equally essential for forest monitoring and accounting for changes in carbon stock [45].

Chapter 3

Methodology

3.1. Data sources and attributes

Figure 8 and table 1 gives an overview of the datasets used in the study and their specifications, in particular the properties of satellite sensors are also given.

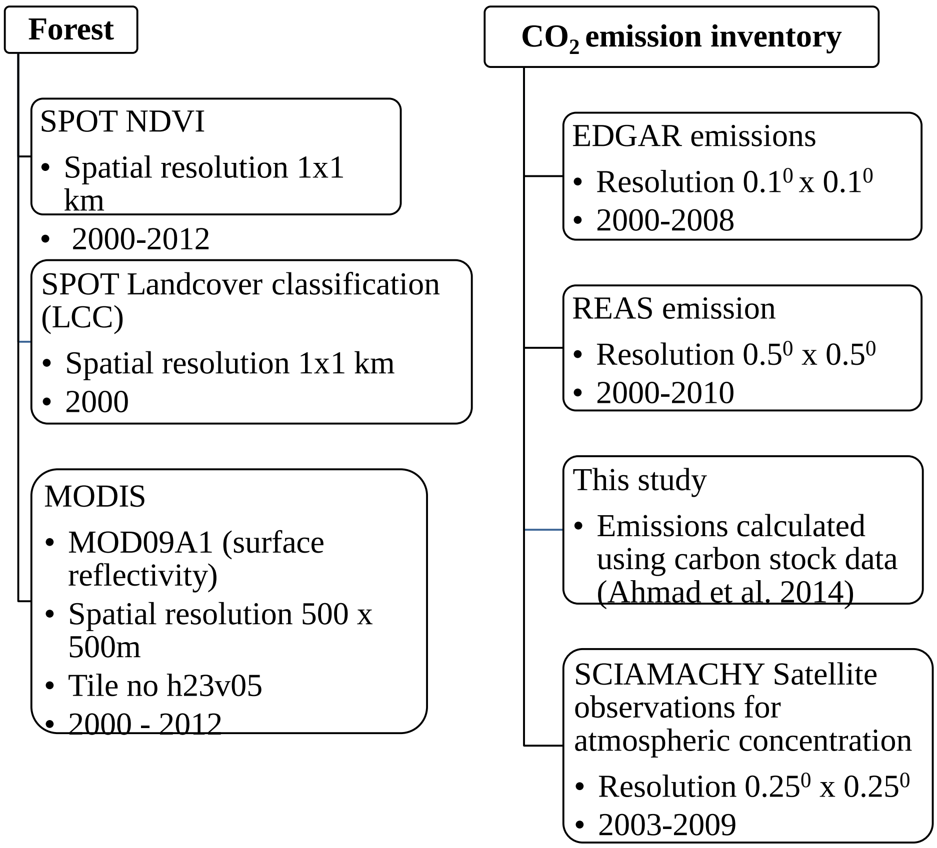


Figure 8: Data used in this study along with its parameters

Table 1: Satellite sensors and their properties

Properties	SPOT (vegetation)	MODIS Terra	SCIAMACHY
Spatial resolution	1 x 1 km	500 x 500 m	0.25^0 x 0.25^0
Swath width	2250 km	2330 km	960 km
Temporal resolution	10 days	8 days	6 days
Temporal coverage	1998 to present	2000 to present	2002 to 2012
Red and NIR bands	2 & 3 610-680nm & 780-890nm	1 & 2 620-670nm & 840-880nm	-
Spectral range	4 bands (0.43 to 1.74 µm)	36 bands (0.405 to 14.385 µm)	240 to 2380 nm
Data quality assessment	85 %[1] Accurate	89.32 % [2] Accurate	70% Accurate

3.2. Forest data processing on ERDAS Imagine, ArcGIS and IDRISI Selva

Satellite images for the months of June were stacked and re-projected to WGS 84 UTM zone 43 north, followed by NDVI calculation using ERDAS Imagine 2013 using formula in Eq.(1). To calculate NDVI, red and NIR (near infrared) bands were used which are 1 (red) and 2 (NIR) for MODIS and 2 (red) and 3 (NIR) for SPOT sensors.

$$NDVI = NIR – Red/NIR + Red \qquad \text{Eq.1}$$

[1] Indian Institute of Remote Sensing. 2003. South Central Asia. Global land cover 2000
[2] http://landval.gsfc.nasa.gov/ProductStatus.php?ProductID=MOD09

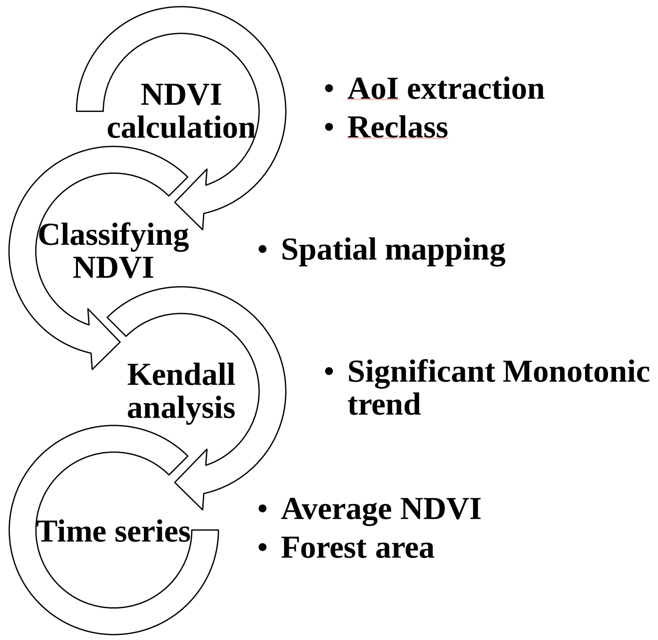


Figure 9: SPOT and MODIS data processing

NDVI [46] are derived from NIR and Red spectral wavelengths. It acts as a biophysical parameter linking photosynthetic activity of vegetation with greenness which is based on chlorophyll content and energy absorption by the plant [47]. It provides a significant basis to assess seasonal and inter-annual changes in both vegetation and photosynthetic activities [48]. Although, NDVI differencing is a successful change-detection method [49], it has limitations in estimating the variations in canopy structure and architecture. As it is potentially affected by soil background and saturates at high biomass [50, 48] and at intermediate leaf area index (LAI) values [51].

Moderate Resolution Imaging Spectroradiometer (MODIS) [52] and Satellite Probatoire d'Observation de la Terre (SPOT) [53,54] are widely used for biosphere mapping and other relevant activities [55]. SPOT NDVI product was developed by the Institute of Geographic Information System: National University of Science and Technology (NUST). MODIS surface reflectivity product was obtained from Land Processes Distributed Active Archive Centre (LP DAAC).

As Dir is in the northern part of the country where temperatures are quite low therefore summer time is ideal to study vegetation, its growth will be maximum and snow cover will be minimum. Mann Kendall test was performed, using IDRISI

Selva, on all NDVI images to assess the statistical significant of calculated spatial and temporal trends. Yearly spatial maps of temperate conifer forests were developed with classification of NDVI, in way that it compares well with SPOT LCC product for year 2000. Thus, pixels with NDVI values 0.35 and above for SPOT were assigned as temperate conifer forests while the rest of pixels were referred as mixed forests. Similar procedure was repeated for MODIS datasets and annual vegetation maps were developed. For MODIS area of one pixel is 21 ha and for SPOT it is 100 ha. Area of forest cover was calculated by using the formula given by Eq. (2):

$$\text{Forest covered Area} = (\text{No of pixels with Forests})\ (\text{Area of one pixel}) \qquad \text{Eq.2}$$

3.3. CO_2 data processing using ERDAS Imagine and ArcGIS

Yearly CO_2 emission inventory data of EDGAR[3] and REAS[4] were downloaded and extracted over the study site by using ArcGIS v10.2. Time series were developed to visualize the temporal evolution of CO_2 emissions from various sectors over the Dir district. For EDGAR and REAS yearly files were used. For SCIAMACHY [56] monthly files were used which were only of June.

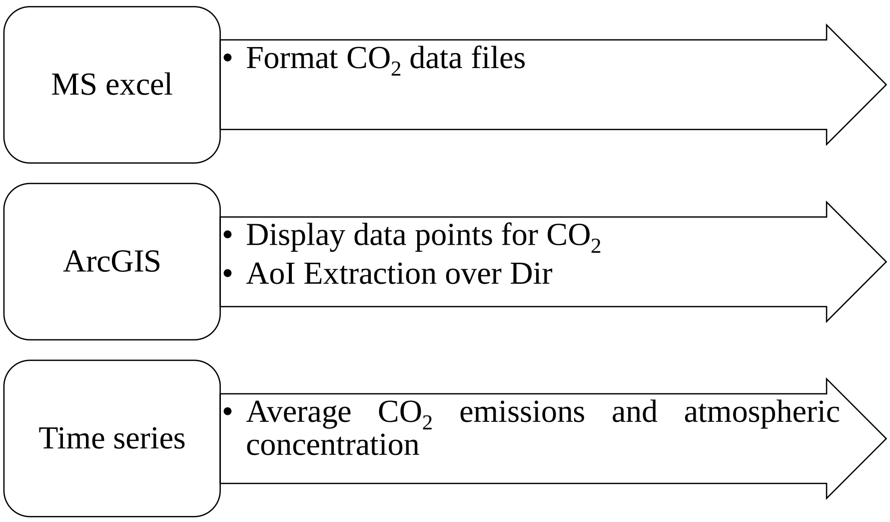


Figure 10: CO_2 data processing

[3] http://edgar.jrc.ec.europa.eu/overview.php?v=42
[4] http://www.jamstec.go.jp/frsgc/research/d4/emission.htm

3.4. Quantifying CO_2 emissions from LULUC

To calculate CO_2 emissions from land use land use change (LULUC) standard formula provided by IPCC [57] given in Eq. (3) was used. Carbon stock data used in this study is for above ground biomass; therefore, the emissions/sequestrations are representative only from changes in above ground carbon pool excluding soil.

$$CO_2 \text{ emissions/year} = \text{Change in Forest Area (hectare)} \times \text{Carbon Stock per hector} \quad \text{Eq. 3}$$

Chapter 4

Results and discussion

4.1. Selection of temperate conifer forests

According to figure 11 temperate conifer forests are abundant in Dir, relative to other forest types, therefore they were selected as the target specie for this study. SPOT LCC product for 2000 was compared SPOT NDVI for 2000 to achieve optimum spatial consistency for temperate conifer forests. The results showed that pixels with NDVI values 0.35 and above are very well representative for temperate conifer forests.

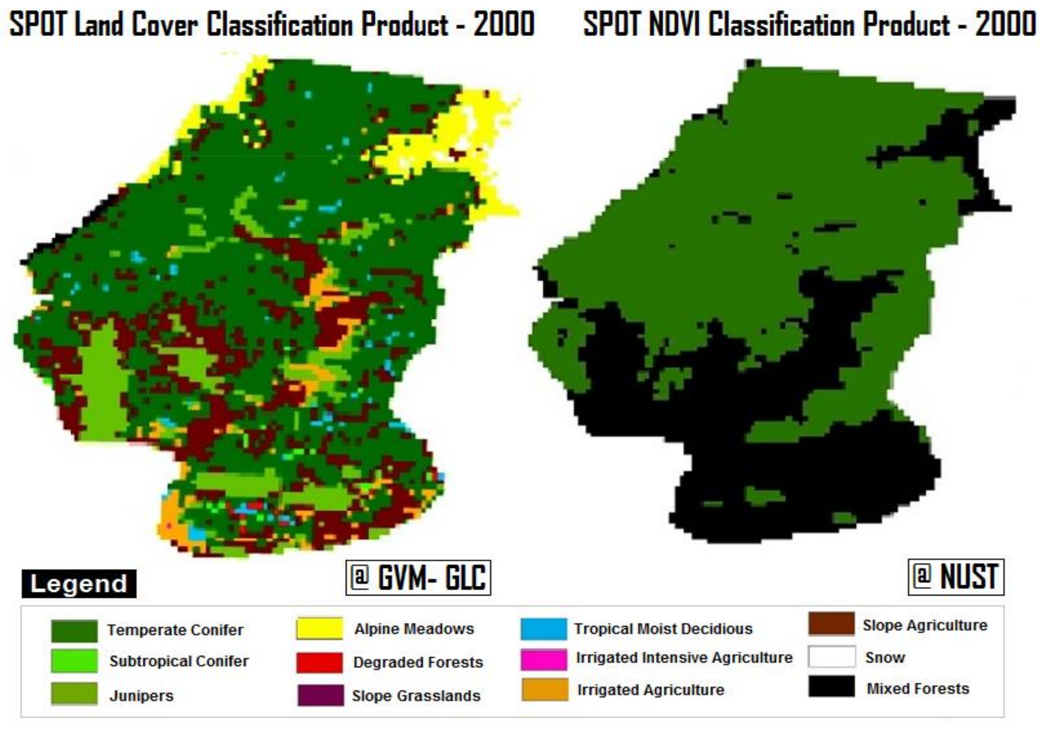


Figure 11. Land cover classification (LCC) of Dir, Pakistan obtained from Global Vegetation Monitoring (GVM)[5] unit (GLC, 2000) compared with SPOT NDVI developed at NUST for year 2000

[5] http://bioval.jrc.ec.europa.eu/products/glc2000/products.php

4.2. Spatial maps and Mann- Kendall test on NDVI

Mann Kendall test was applied on all NDVI images to assess the statistical significance of calculated NDVI trend for both the datasets. According to figure 12 upward or increasing trend in NDVI is dominant for both SPOT and MODIS. However, both data sets differ from each other in the context of having total number of pixel with significant trend. SPOT data exhibited more pixels with increasing trend (with SPOT having more pixels with 95% confidence level) as compared to MODIS and might be a more reliable dataset over the study area.

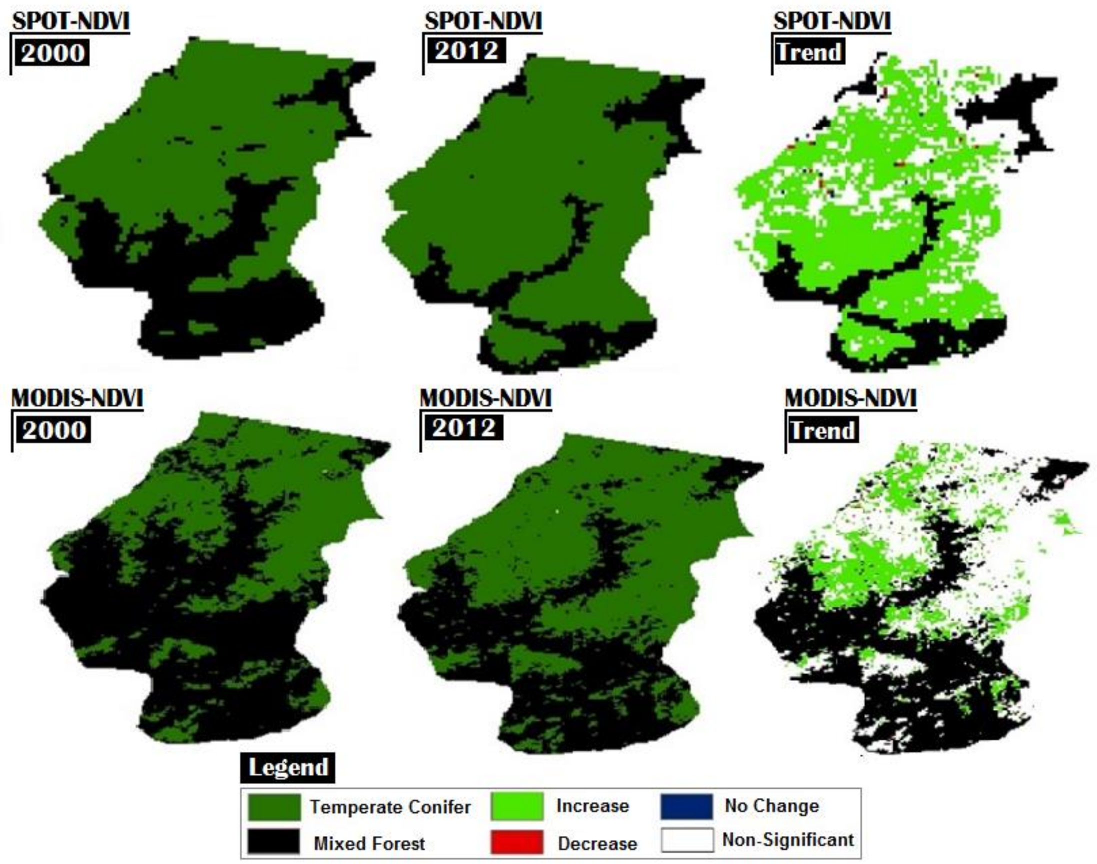
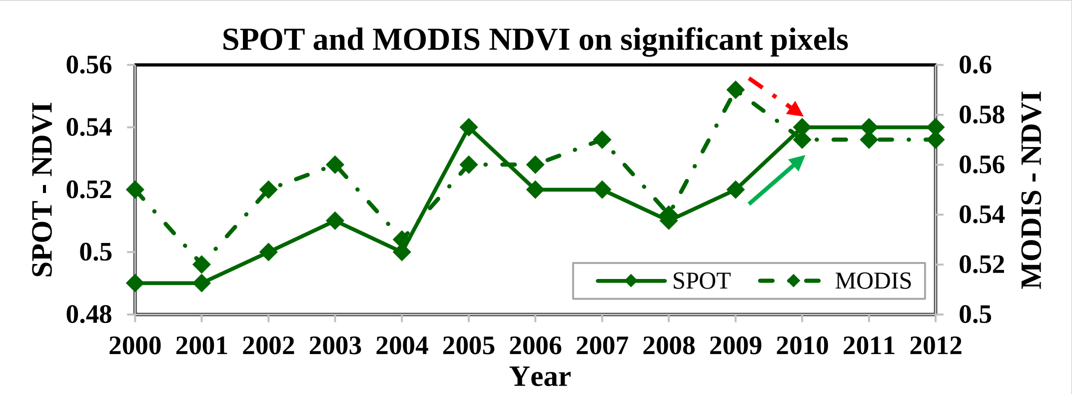


Figure 12: Forest cover over Dir between 2000 and 2012 based on SPOT and MODIS vegetation index. Maps of spatial trends for both SPOT and MODIS NDVI on pixels with 95% confidence level are also presented

4.3. Forest area and NDVI time series

Figure 13 presents the evolution of NDVI over selected region during the time period of 2000-2012. Time series was prepared by calculating mean NDVI only over the pixels with 95% confidence level and forest type of temperate conifers.

Regression analysis was performed in order to calculate the NDVI trend. Both data sets have shown a fairly consistent increase of 9.7 percent and 11.6 percent for MODIS and SPOT, respectively. However, there exist some inter-annual inconsistencies. Especially, during the year 2010 where SPOT has shown an increase in NDVI (Green arrow in figure 13) while MODIS has exhibited a decrease (red arrow in figure 13). Similar temporal increase in forest cover (calculated by using formula given in Eq.2) is reflected from 2000 to 2012 with 73 percent and 139 percent from SPOT and MODIS data, respectively. Moreover, both datasets show that most significant changes in forest area has taken place in the period before 2006 (figure 13b).



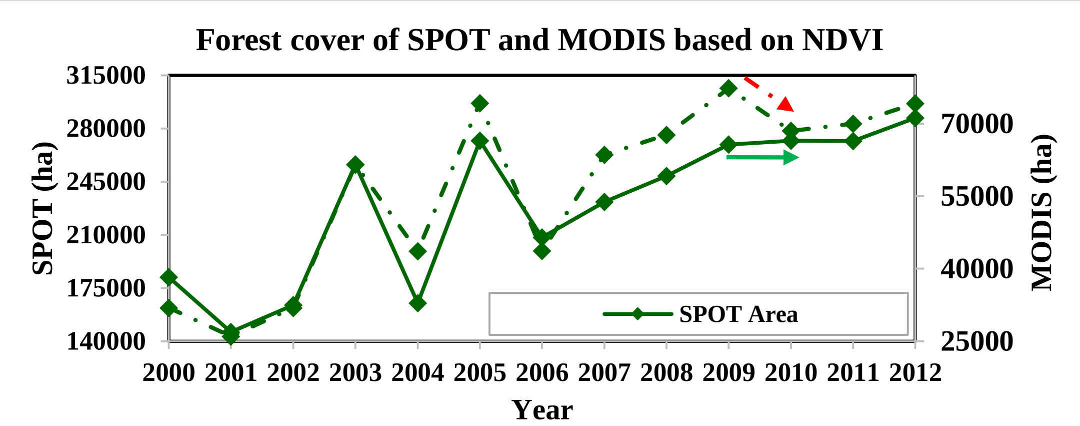


Figure 13: Average NDVI on pixels with 95% significance of monotonic upward trend (top). Variation in forest cover over Dir between 2000 and 2012 (bottom). Red arrow is showing decrease in MODIS NDVI whereas green arrow is showing increase in SPOT NDVI (bottom)

A discrepancy was observed between years 2009 and 2010 where SPOT and MODIS show opposite trend. Section 4.4. investigates the actual change in vegetation cover and NDVI between the years 2009 and 2010.

4.4. Comparison of SPOT and MODIS with Google Earth imagery

To investigate the opposite trend of SPOT and MODIS, change in vegetation was visualized on Google earth images and were compared with actual NDVI values for years 2009 and 2010 from both sensors over a randomly selected area. According to the Google earth imagery in figure 14 vegetation activity/spread has significantly increased between 2009 and 2010.

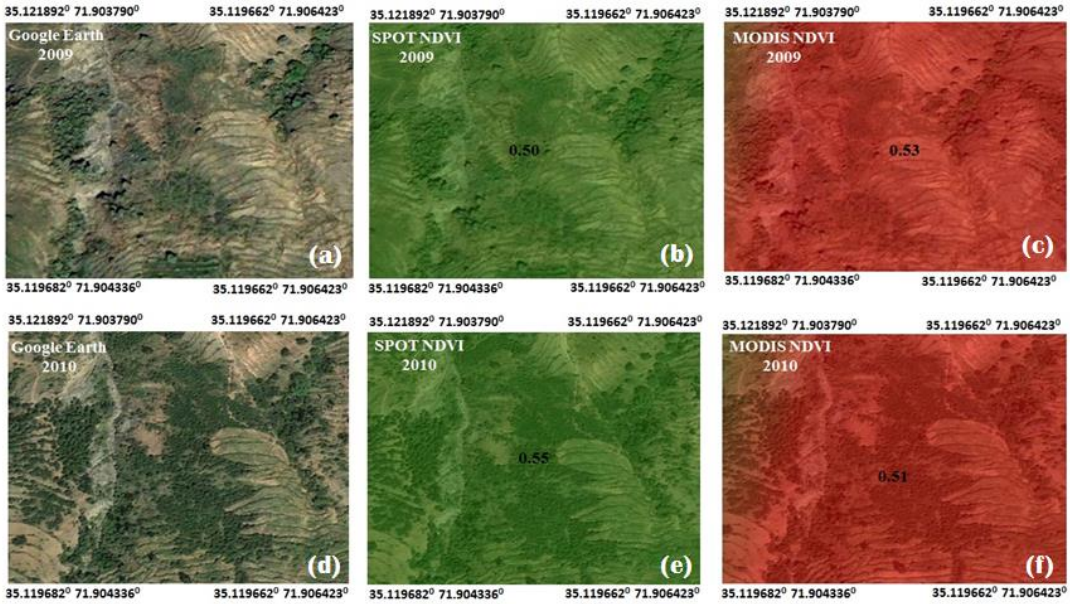


Figure 14: Google earth imagery showing increase in vegetation from year 2009 to 2010. SPOT NDVI has also exhibited increased NDVI for year 2010 as indicated by green color, whereas MODIS NDVI exhibited a further decreased vegetation, (red color). Numbers are indicating the mean vegetation index over the selected region for both instruments

Similar trend was observed in the SPOT NDVI over the selected area (figure 14 b & d). However MODIS data exhibited the region with non-vegetation (figure 14 c and f) and less NDVI with a further decrease in the vegetation activity during the year 2010. The comparison presented in figure 14 clearly indicates that MODIS instrument was unable to detect changes in vegetation activity as compared to SPOT instrument. As mentioned earlier, MODIS instrument has certain limitations and is largely affected by soil background and saturates at high biomass [48, 50] and at intermediate leaf area index (LAI) values [51]. This discrepancy in MODIS NDVI can be associated with canopy background noise issue [60,61], especially when a scene is comprised of scattered forest and vegetation.

4.5. Comparison of calculated forest area with CO_2 emissions

EDGAR and REAS are widely used global emission inventories. CO_2 emissions from anthropogenic activities and land uses change sectors over the study area were extracted and compared with each other and forest cover. Figure 15 shows increasing trends in CO_2 emissions (REAS anthropogenic, EDGAR total and land use change) in contrast to the forest area from both MODIS and SPOT. In principal, CO_2 emissions should have decreased with increase in vegetation activity (NDVI) and forest area.

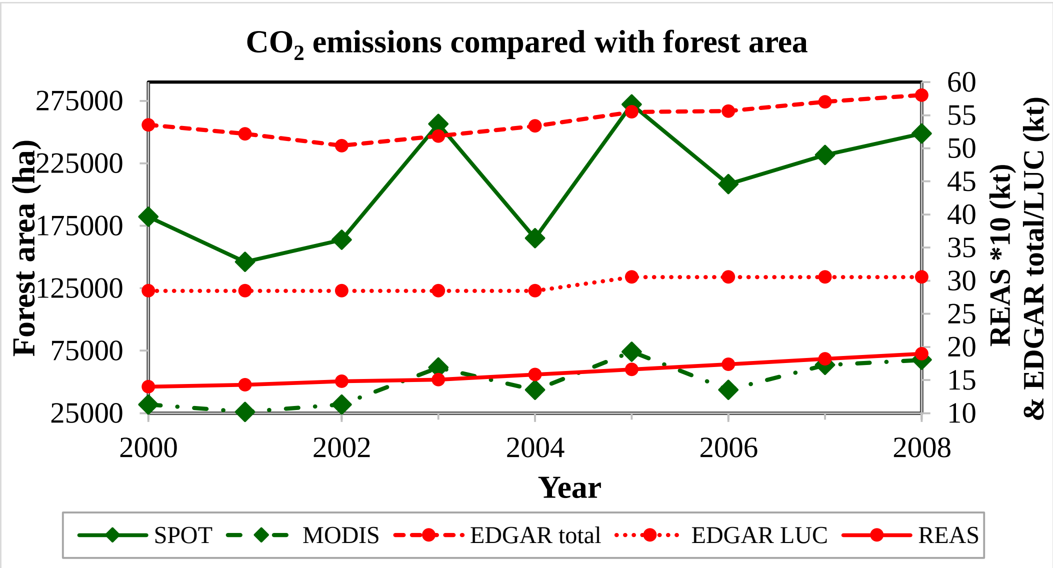


Figure 15: Comparison of CO_2 emission data from EDGAR total, EDGAR land use change (LUC) and REAS anthropogenic emissions with yearly forest area cover of Dir

EDGAR inventories are indicating a constant amount of CO_2 emissions with sudden jump during year 2005. It indicates that there is a strong need to quantify the CO_2 emissions from other sectors (e.g. vehicle, traffic, agriculture etc.) over the study area as well. As Pakistan has a poor record of its sectoral GHG emissions especially from LUC, therefore accuracy of CO_2 emission inventory is questionable. Although, Dir is comparatively less developed and has almost negligible industrial activities but still due to geo-political (ongoing Afghan war) situation and longer CO_2 lifetime it is vital to constraints the emissions from all sectors. Furthermore, the global CO_2 emission inventories are not well representative over Pakistan.

4.6. Comparison of calculated forest area with SCIAMACHY observations of atmospheric CO_2 concentration

There is an overall 2.5% increase in CO_2 concentrations between 2003 and 2009, whereas the forest area is increasing in this time period. Another observation made is that atmospheric CO_2 is relatively higher for years 2003, 2006 and 2009 which has been discussed in section 4.6.1. Based on figure 16, SCIAMACHY observations are not consistent to yearly forest area variation mainly because of missing/very few data points over Dir are available and thus leading to use interpolated global data.

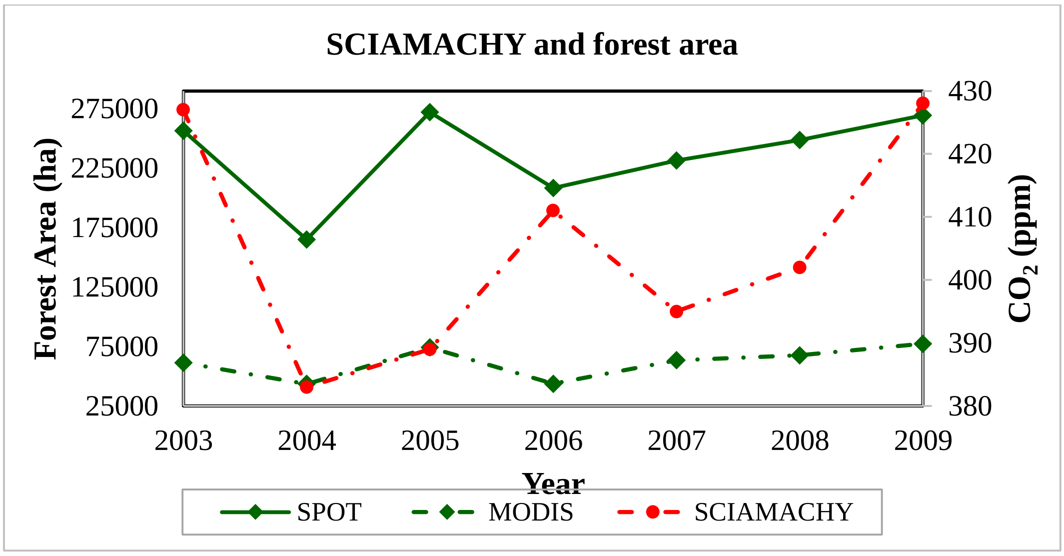


Figure 16: Comparison of atmospheric CO_2 concentration with calculated forest area

4.6.1. Validating high CO_2 concentrations with CO_2 emissions, wind and fire data

There is a poor comparison between CO_2 emissions and atmospheric concentration (figure 17) mainly due to mission data points over Dir and use of interpolated data. Therefore emission inventory of EDGAR and REAS cannot account for high CO_2 concentration in 2003, 2006 and 2009.

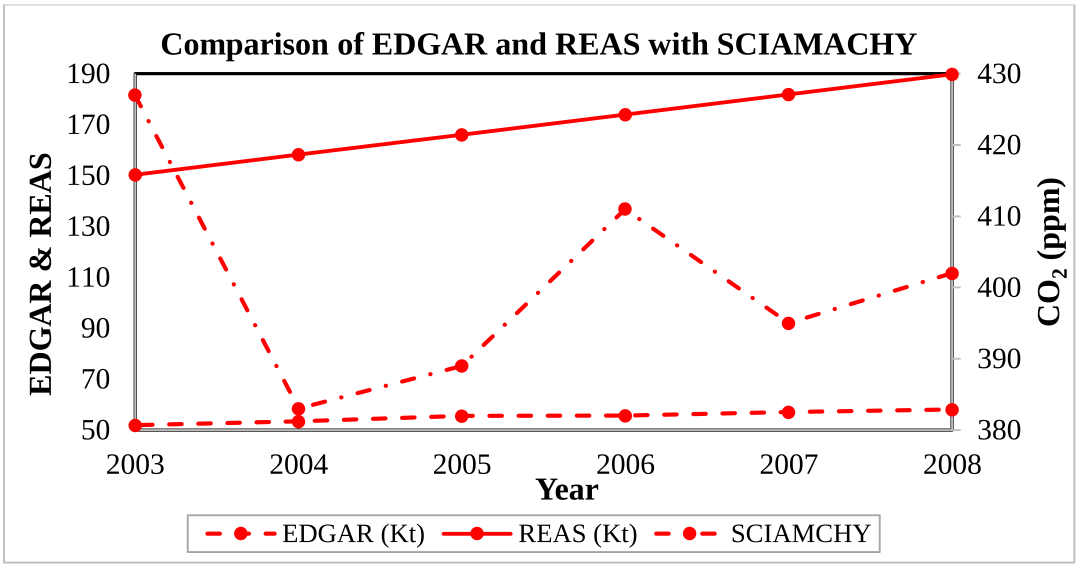


Figure 17: EDGAR total and REAS anthropogenic emissions compared with atmospheric CO_2 concentrations

According to figure 18 there are fire events scattered over or near Dir, for 2006 and 2009 in particular. However the wind direction is not supporting any transport effect. In fact, it might has caused a transport of pollutants from Dir to the neighboring regions.

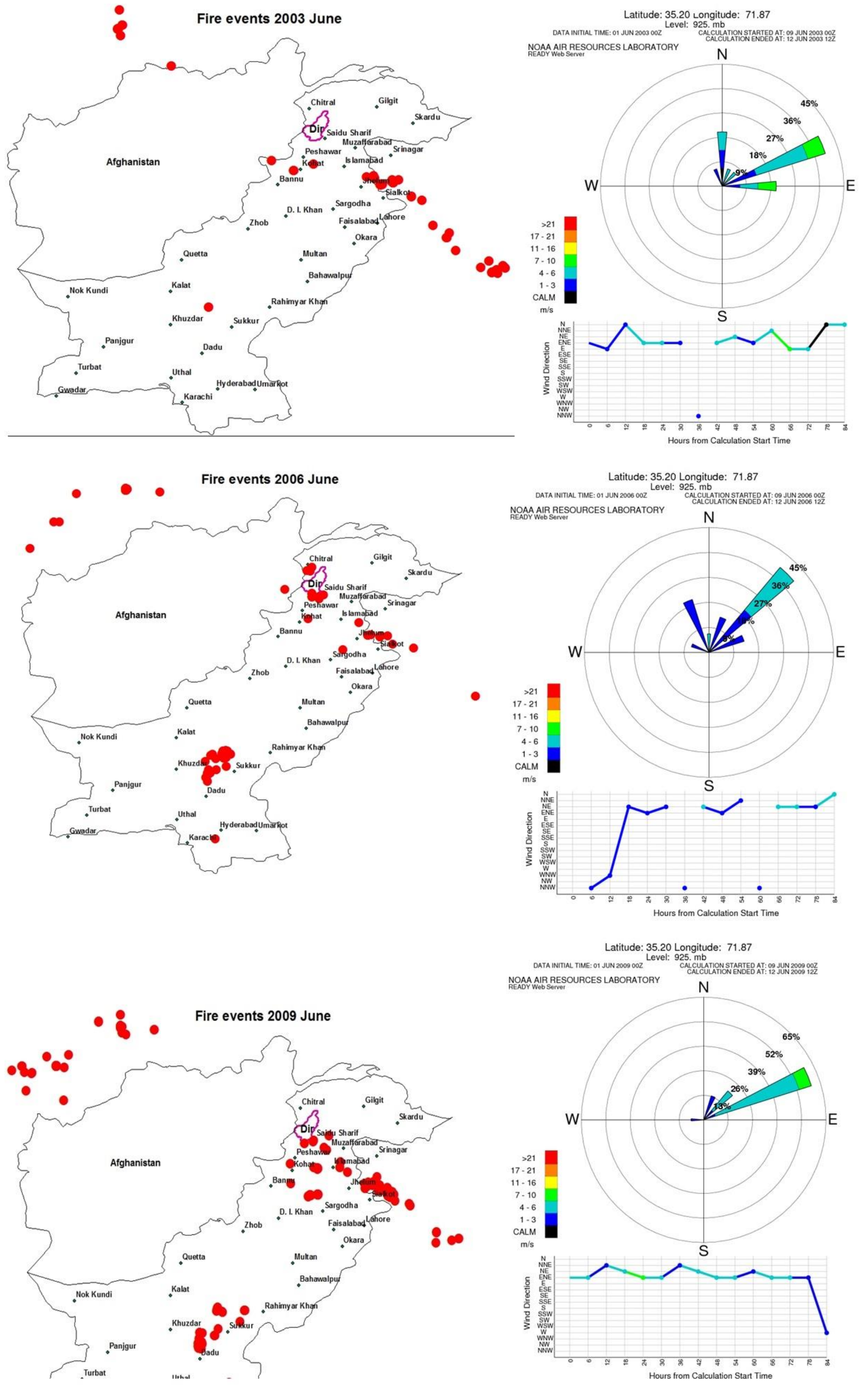


Figure 18: Windrose (obtained from ARL NOAA[6]) and fire events (Fire data obtained from NASA Goddard Space Flight Centre[7])

[6] Ready.arl.noaa.gov/ready.atem.php

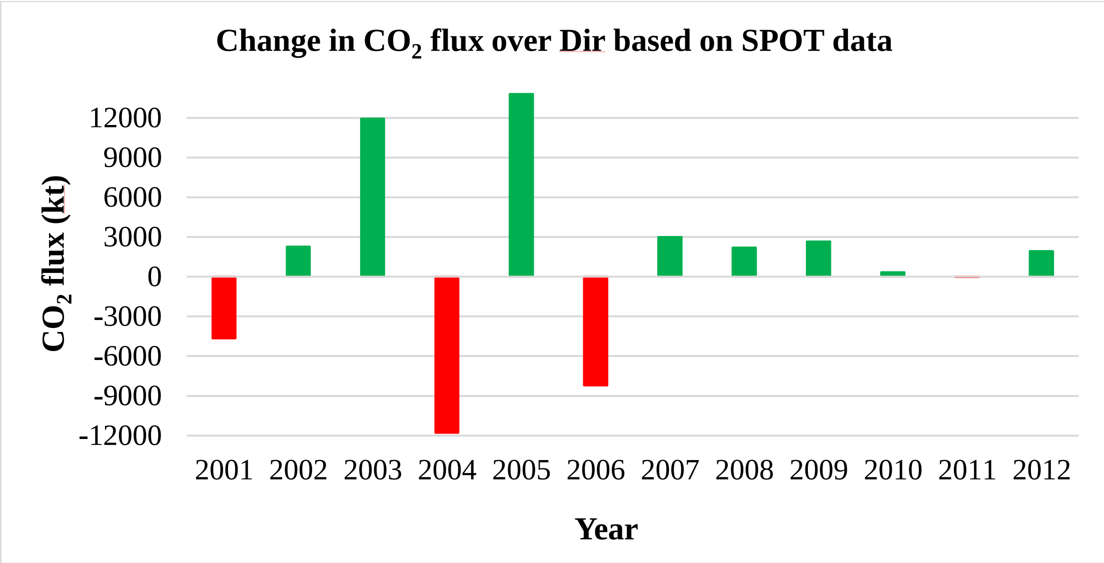
[7] http://viirsland.gsfc.nasa.gov/Products/Fire.html

4.7. Calculating CO_2 emissions and sequestration over Dir using carbon stock data

Table 2 shows change in forest area with respect to preceding year and the years in which deforestation has occurred. Yearly carbon stock emissions were calculated (figure 19) using the standard IPCC formula, given in Eq. (3), used to find out total emissions, total sequestration and net result between 2000 and 2012. Emissions or addition of CO_2 in atmosphere in a particular year is due to deforestation and sequestration or absorption of CO_2 from atmosphere is because of increased forest cover. Carbon stock 0.129 kt/ha [8] for temperate conifer was used along with change in forest area with respect to base year 2000. The change in forest area was calculated from MODIS and SPOT pixels within 95% confidence interval only.

Table 2: **Calculations of change in forest area with respect to preceding year (negative sign means deforestation/emissions and positive sign means increase in forest area/sequestration)**

Year	Change in Forest Area (ha)		LULUCF Emissions (kt)	
	SPOT	MODIS	SPOT	MODIS
2001	-36200	-5874	-4670	-757
2002	17700	5874	2283.3	757
2003	92700	29625	11958	3821
2004	-91400	-17921	-11790	-2311
2005	107000	30634	13803	3951
2006	-63700	-30569	-8217	-3943
2007	23300	19893	3005	2566
2008	17100	4116	2205	530
2009	20600	9668	2657	1247
2010	2700	-8832	348	-1139
2011	-200	1500	-25	193
2012	15100	4160	1947	536
Total Emissions (kt)			-24703	-8152
Total Sequestration (kt)			38210	13605
Net Sequestration (kt)			13506	5453



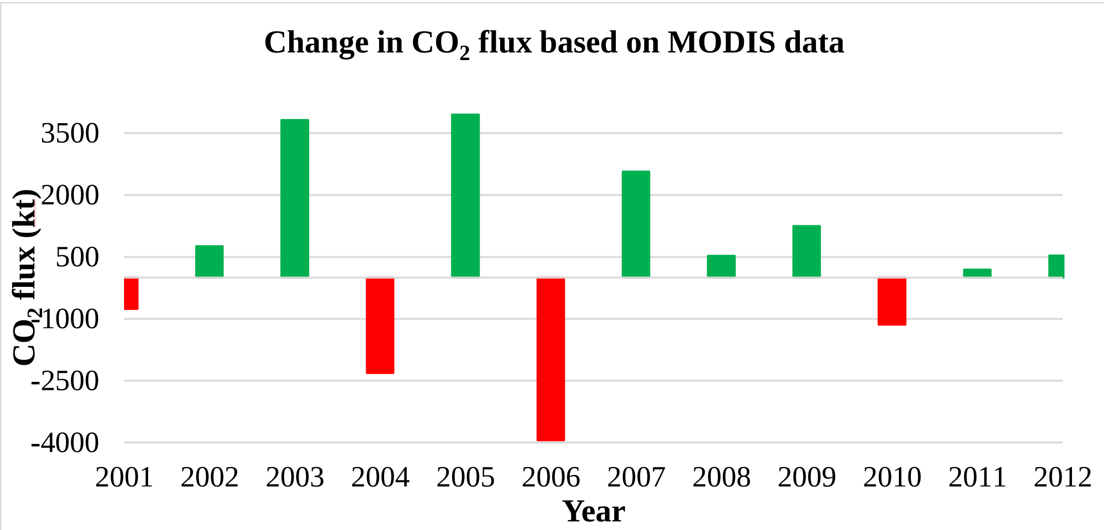


Figure 19: Yearly carbon stock emissions based on SPOT (top) and MODIS (bottom)

4.9. Carbon Credit Potential

In general, vegetation activity (NDVI) and calculated forest cover over Dir district has increased from 2000 to 2012. In Table 2, CO_2 emissions from LULUCF for each individual year are calculated with respect to forest cover from previous year. It is obvious from the statistics presented in figure 20, increase in calculated forest cover from both instruments has led to net sequestration of CO_2 of 13506 kt and 5453 kt for SPOT and MODIS, respectively. NDVI trend based on SPOT data is more significant than that of MODIS, hence the net sequestration estimated using SPOT is relatively more reliable.

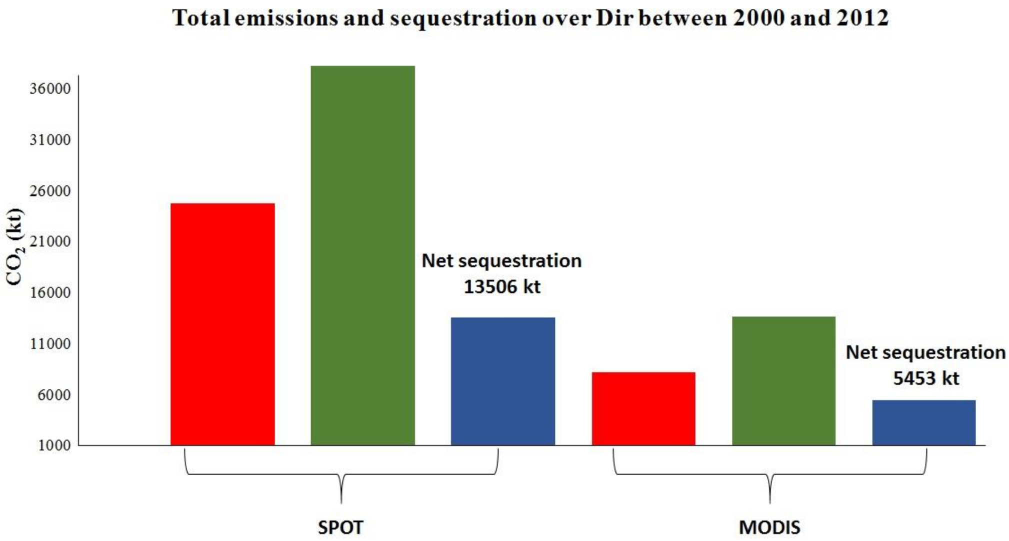


Figure 20: Total emissions (red) and sequestration (green) and net sequestration (blue) of CO_2

As one ton of CO_2 is equal to one carbon credit therefore, total number of carbon credit has also increased over the study area with respect to base year 2000. When sold in international carbon market, using \$ 6.7/CO_2/t [62], can bring in a revenue (figure 21) worth Rs 9 billion in Pakistan and to the forest dependent community of Dir, district.

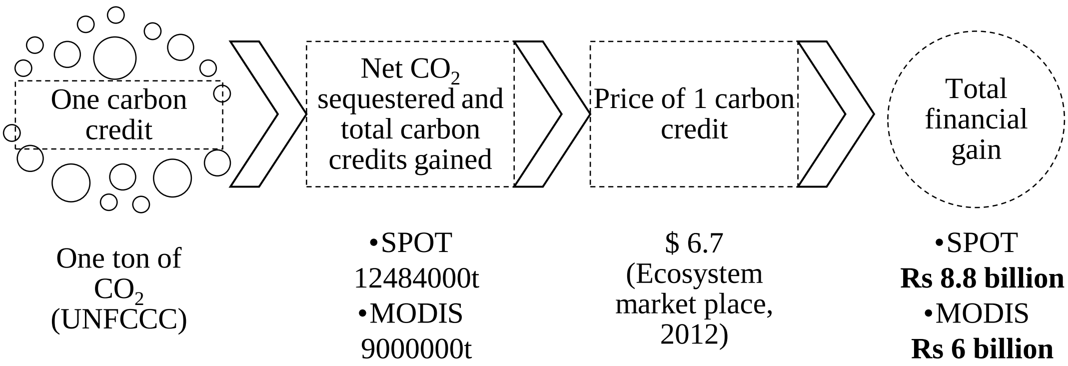


Figure 21: Financial potential of temperate conifer forests of Dir in terms of REDD+ between 2000 and 2012 calculated by multiplying price of one carbon credit with total number for credits (tons)

Conclusion and recommendations

Conclusion

- Overall forest area and NDVI has increased between 2000 and 2012 over Dir, Pakistan and substantial amount of CO_2 has been sequestered.
- The observed increase in NDVI is statistically significant (95 % confidence interval) although MODIS and SPOT differ quantitatively.
- EDGAR and REAS CO_2 emissions are not consistent with increase in forest cover and NDVI over Dir region.
- Global CO_2 emissions data is not representative over AOI.
- SCIAMACHY CO_2 observations are not consistent with forest cover and calculated NDVI over Dir Region. Less observations, Regional Fire and Wind direction might have equally contributed the observed CO_2 concentrations.
- There is strong need to constraint CO_2 emissions from all sources over the study area.
- Pakistan has huge potential of REDD+ implementation and can generate significant amount of revenue by preserving its forests.
- Earned revenue from carbon credits can be used to motivate forest dependent community to further involve them in REDD+. This will help attain sustainability in the lives of forest dependent communities, forests management and global GHG mitigation strategies.

Recommendations

- Perform supervised classification/OBI (object based image) analysis on high resolution images.
- Perform ground truthing for accurate biomass and carbon stock measurements for all seasons and forest types existing the study area.
- Extend study to other forest types such as Broad leaved temperate conifer or Mangrove forests.
- Consider other sources of anthropogenic emissions like industry and transport.

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